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Lewis et al.

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(54) **SYSTEM AND METHOD FOR DISAMBIGUATION OF INTERNET-OF-THINGS DEVICES**

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H04W 8/22	(2009.01)
H04W 60/00	(2009.01)
H04W 64/00	(2009.01)

(52) **U.S. Cl.**
CPC ***H04L 12/282*** (2013.01); ***G06T 7/74*** (2017.01); ***H04W 8/22*** (2013.01); ***H04W 60/00*** (2013.01); ***H04W 64/003*** (2013.01)

(58) **Field of Classification Search**
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See application file for complete search history.

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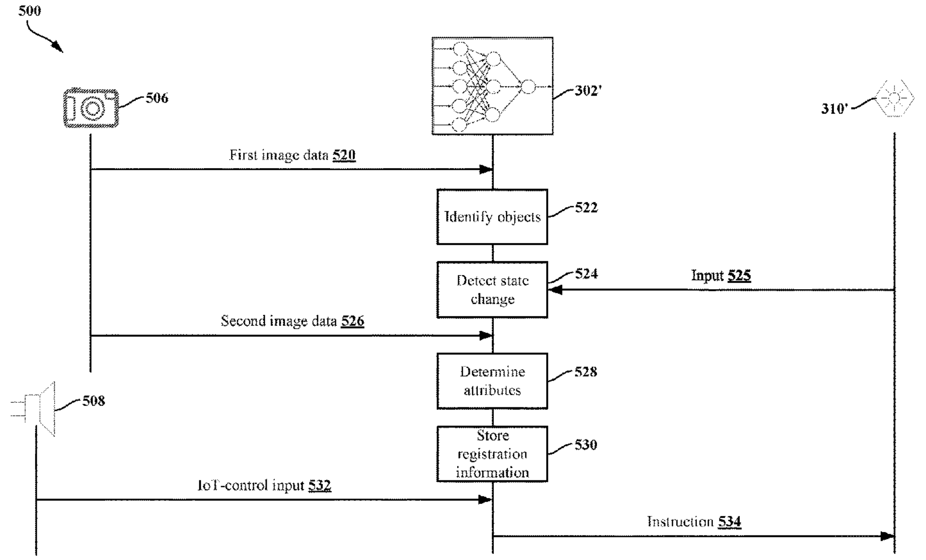
(57) **ABSTRACT**

An apparatus may identify each object of a set of objects included in a first location, wherein the set of objects includes at least one IoT device and at least one other object. The apparatus may determine a first set of attributes for the at least one IoT device. The apparatus may store registration information associated with the at least one IoT device, the registration information including a first identifier associated with the at least one IoT device and including the first set of attributes for the at least one IoT device. The apparatus may obtain an input. The apparatus may determine whether the input corresponds to the at least one IoT device based on the registration information associated with the at least one IoT device. The apparatus may control the at least one IoT device when the input corresponds to the at least one IoT device.

28 Claims, 8 Drawing Sheets



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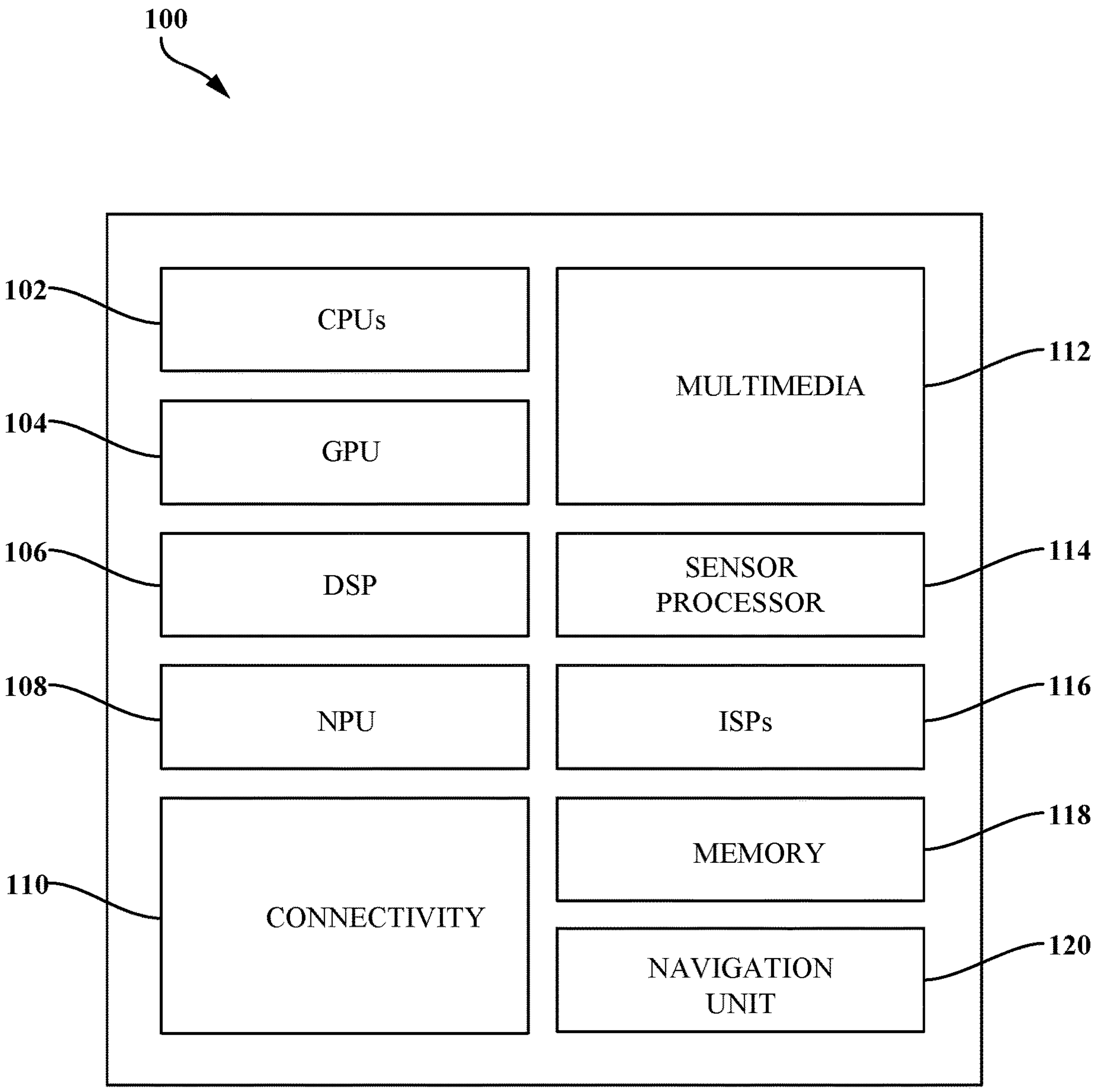
100
102
CPUs
104
GPU
106
DSP
108
NPU
110
CONNECTIVITY
MULTIMEDIA
112
SENSOR PROCESSOR
114
ISPs
116
MEMORY
118
NAVIGATION UNIT
120

FIG. 1

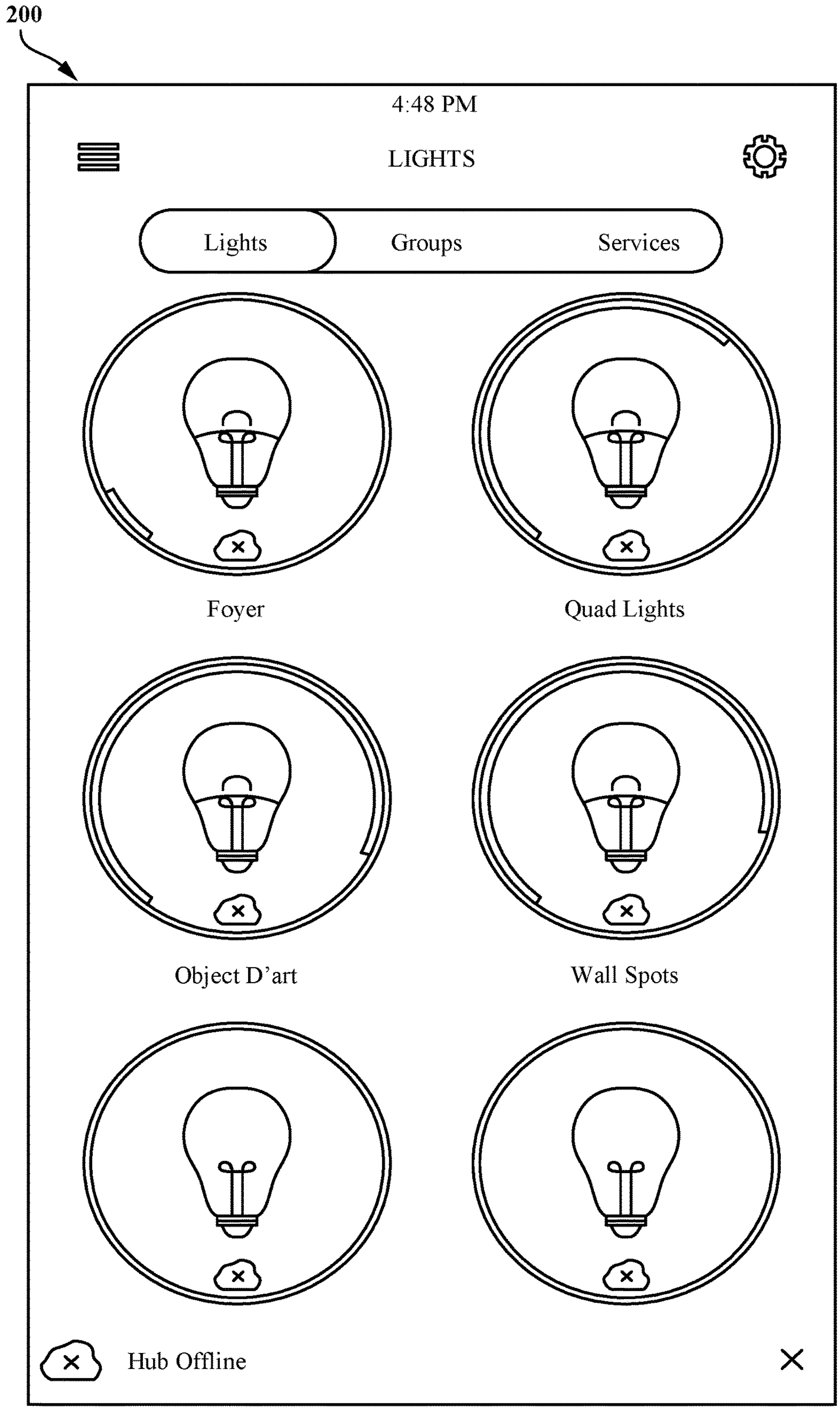
200
4:48 PM
LIGHTS
Lights
Groups
Services
Foyer
Quad Lights
Object D'art
Wall Spots
Hub Offline

FIG. 2

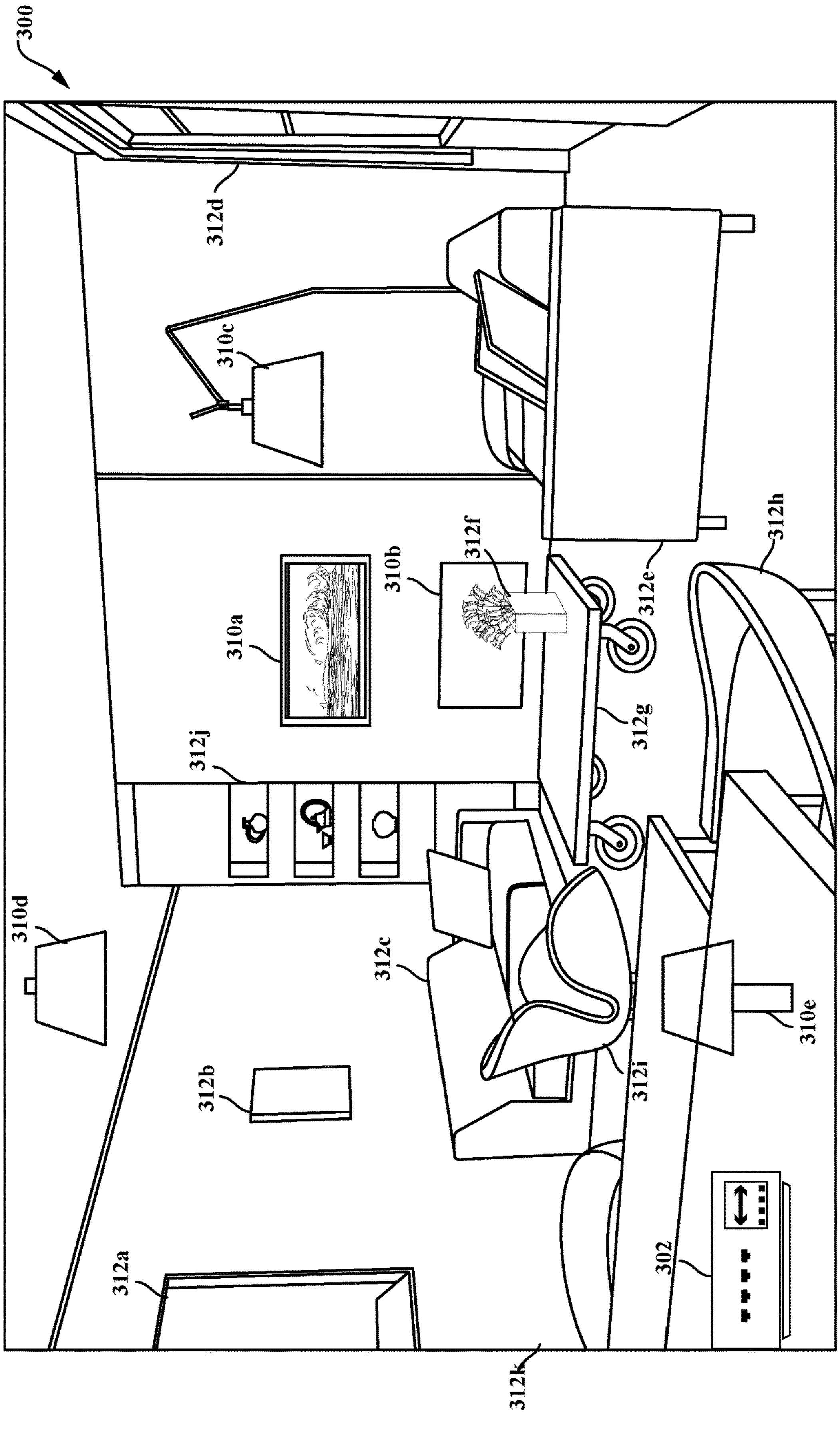
300
312d
310c
312f
310b
310a
312e
312h
312g
312j
310d
312c
312b
312i
310e
312a
302
312k

FIG. 3

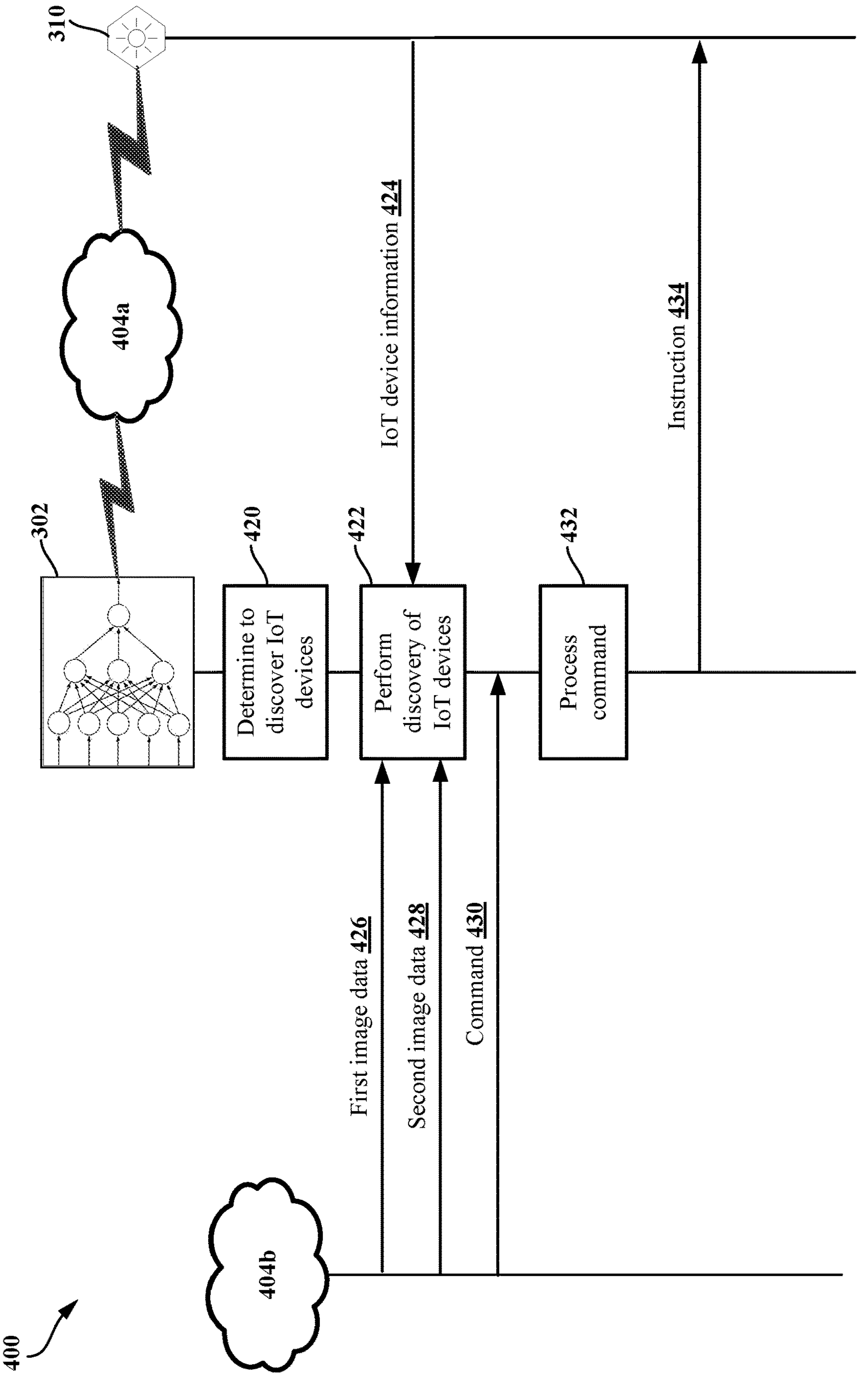
400
404b
302
404a
310
420
Determine to discover IoT devices
422
Perform discovery of IoT devices
432
Process command
First image data 426
Second image data 428
Command 430
IoT device information 424
Instruction 434

FIG. 4

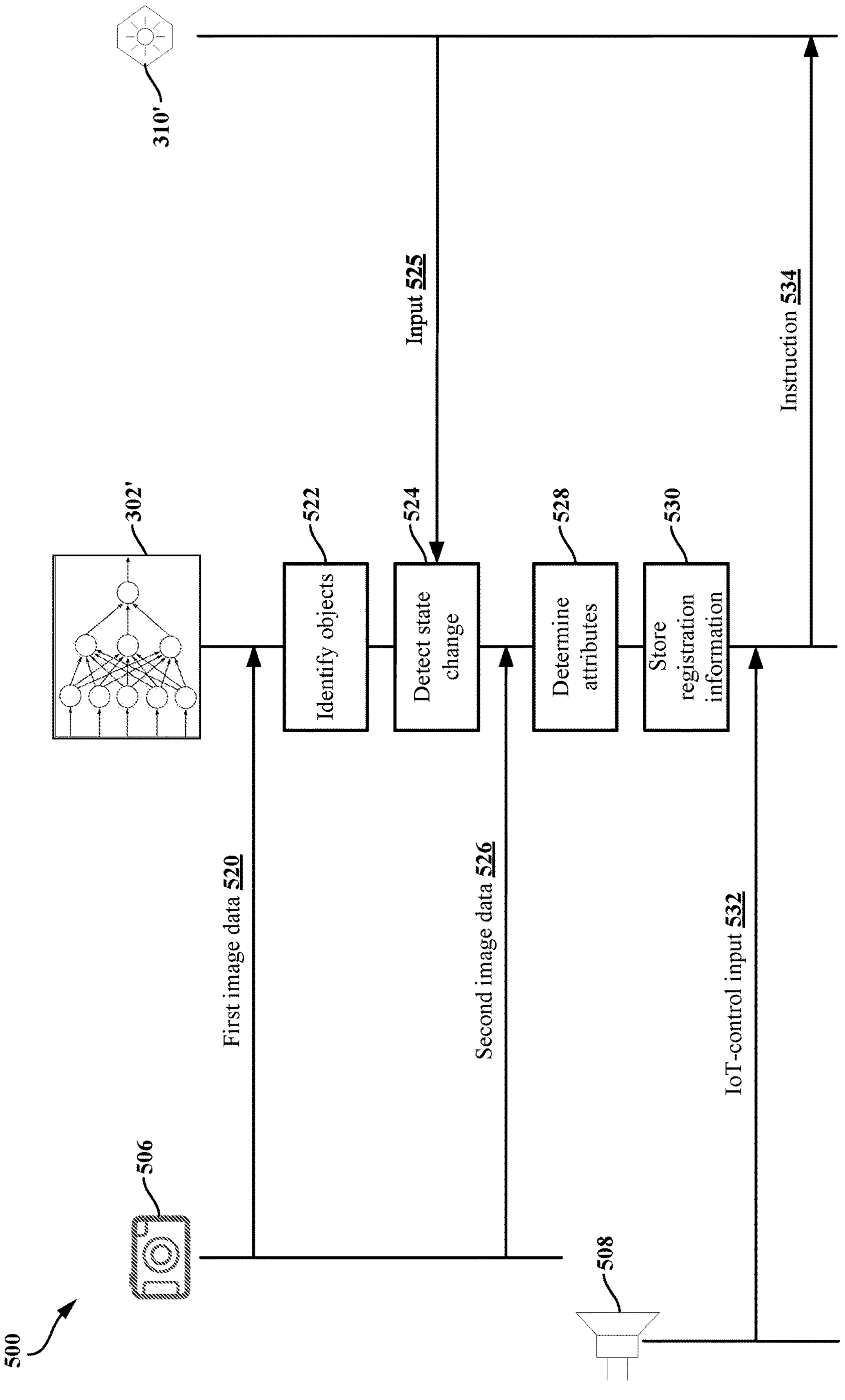
500
506
508
302'
310'
First image data 520
Second image data 526
IoT-control input 532
Identify objects
522
Detect state change
524
Input 525
Determine attributes
528
Store registration information
530
Instruction 534

FIG. 5

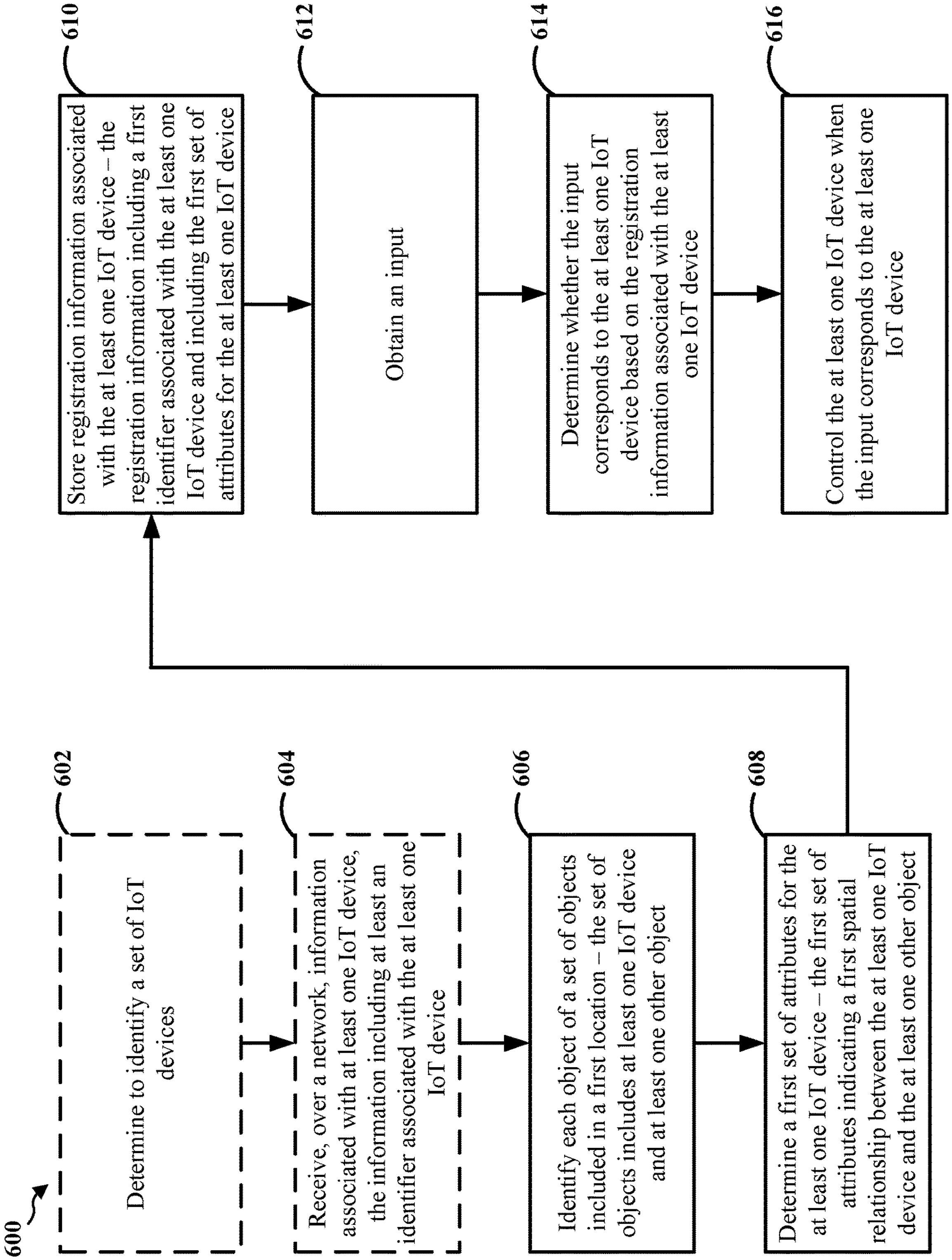
600
602
Determine to identify a set of IoT devices
604
Receive, over a network, information associated with at least one IoT device, the information including at least an identifier associated with the at least one IoT device
606
Identify each object of a set of objects included in a first location – the set of objects includes at least one IoT device and at least one other object
608
Determine a first set of attributes for the at least one IoT device – the first set of attributes indicating a first spatial relationship between the at least one IoT device and the at least one other object
610
Store registration information associated with the at least one IoT device – the registration information including a first identifier associated with the at least one IoT device and including the first set of attributes for the at least one IoT device
612
Obtain an input
614
Determine whether the input corresponds to the at least one IoT device based on the registration information associated with the at least one IoT device
616
Control the at least one IoT device when the input corresponds to the at least one IoT device

FIG. 6

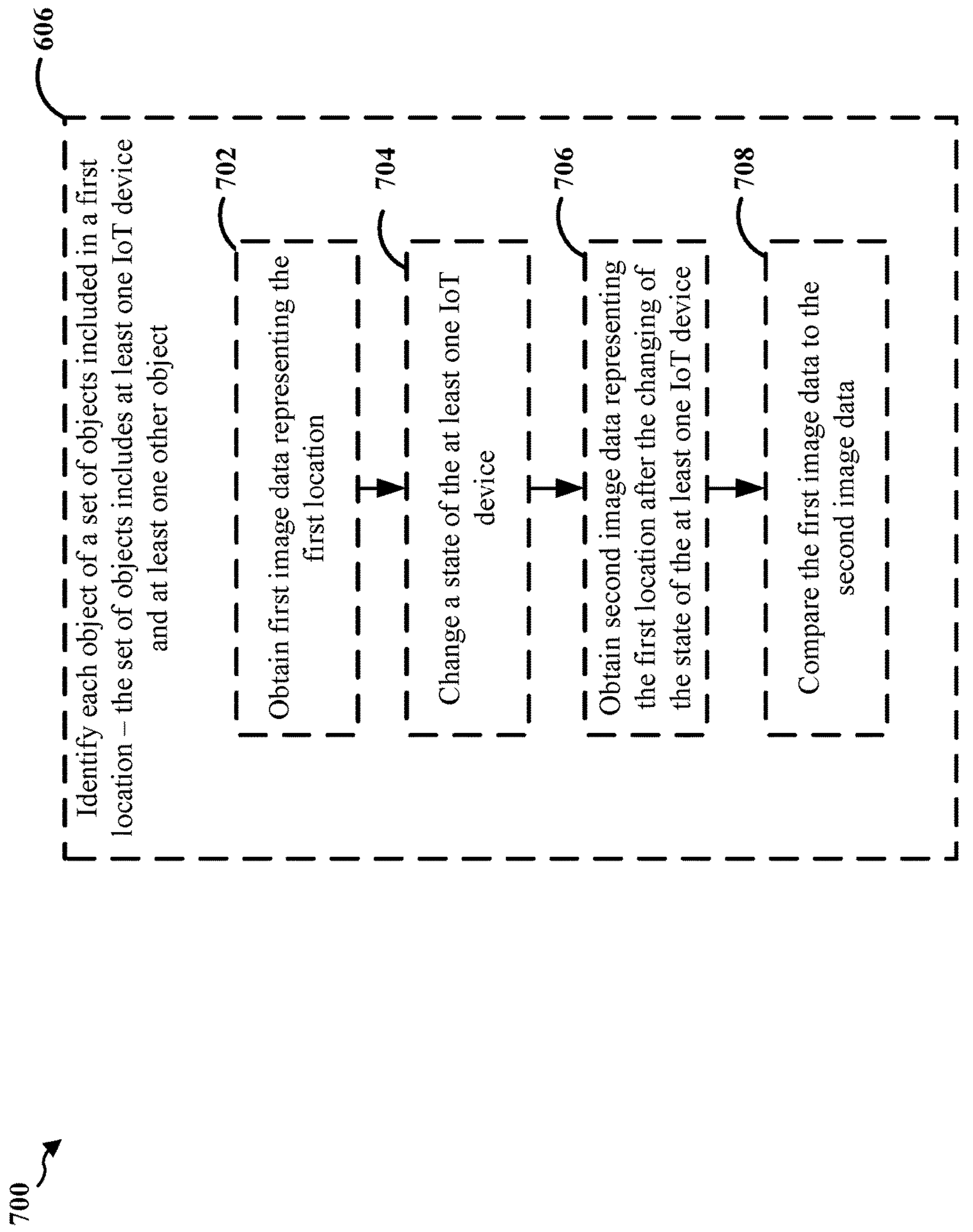
606
Identify each object of a set of objects included in a first location – the set of objects includes at least one IoT device and at least one other object
702
Obtain first image data representing the first location
704
Change a state of the at least one IoT device
706
Obtain second image data representing the first location after the changing of the state of the at least one IoT device
708
Compare the first image data to the second image data
700

FIG. 7

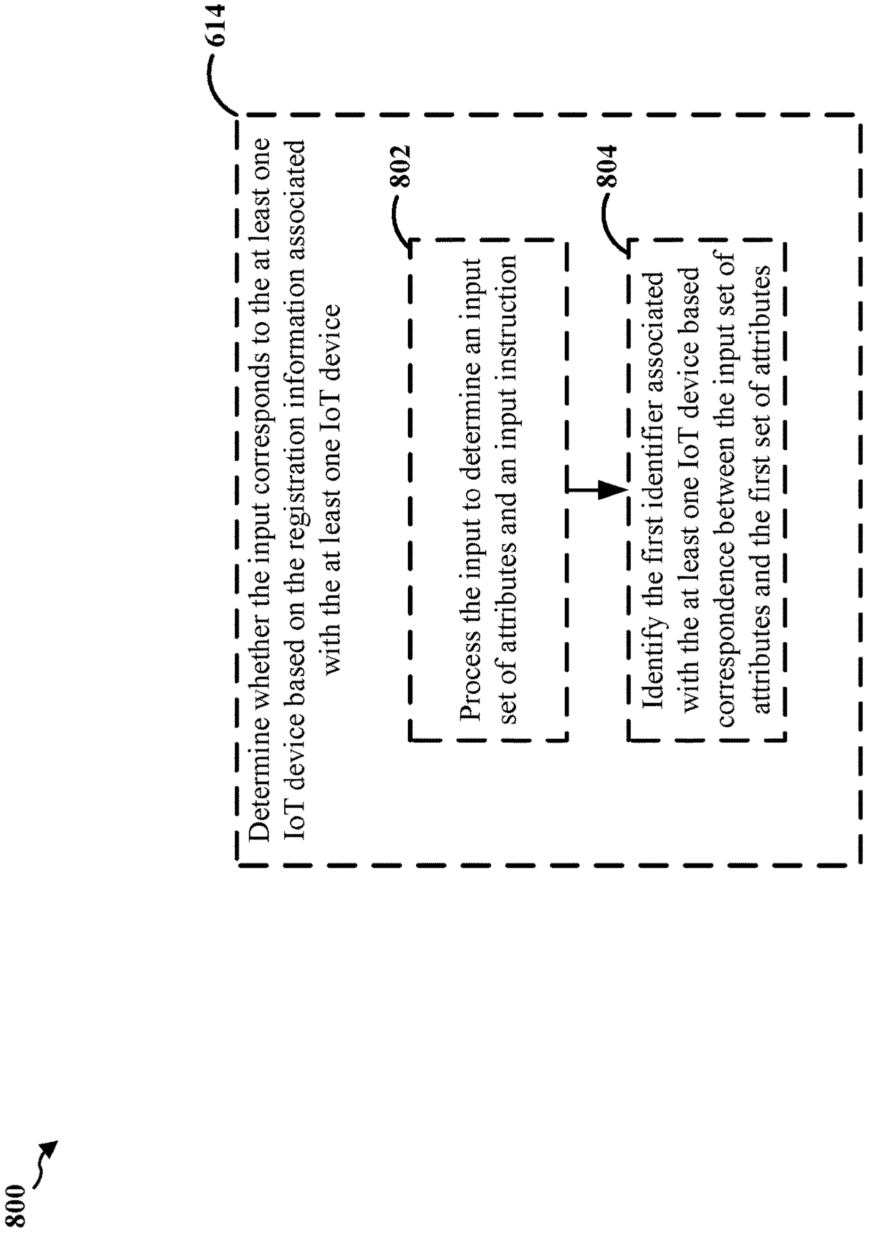
800
614
Determine whether the input corresponds to the at least one IoT device based on the registration information associated with the at least one IoT device
802
Process the input to determine an input set of attributes and an input instruction
804
Identify the first identifier associated with the at least one IoT device based correspondence between the input set of attributes and the first set of attributes

FIG. 8

SYSTEM AND METHOD FOR DISAMBIGUATION OF INTERNET-OF-THINGS DEVICES

BACKGROUND

Field

Certain aspects of the present disclosure generally relate to machine learning and, more particularly, to improving systems and methods of identifying and registering one or more Internet-of-Things devices.

Background

An artificial neural network, which may include an interconnected group of artificial neurons (e.g., neuron models), is a computational device or represents a method to be performed by a computational device.

Convolutional neural networks are a type of feed-forward artificial neural network. Convolutional neural networks may include collections of neurons that each has a receptive field and that collectively tile an input space. Convolutional neural networks (CNNs) have numerous applications. In particular, CNNs have broadly been used in the area of pattern recognition and classification.

Deep neural networks (DNNs) may be trained to recognize a hierarchy of features and so they have increasingly been used in object recognition applications. Other models are also available for object recognition. For example, support vector machines (SVMs) are learning tools that can be applied for classification. Although these solutions achieve excellent results on a number of classification benchmarks, their computational complexity can be prohibitively high. Additionally, training of the models may be challenging.

SUMMARY

The following presents a simplified summary of one or more aspects in order to provide a basic understanding of such aspects. This summary is not an extensive overview of all contemplated aspects, and is intended to neither identify key or critical elements of all aspects nor delineate the scope of any or all aspects. Its sole purpose is to present some concepts of one or more aspects in a simplified form as a prelude to the more detailed description that is presented later.

It should be appreciated by those skilled in the art that this disclosure may be readily utilized as a basis for modifying or designing other structures for carrying out the same purposes of the present disclosure. It should also be realized by those skilled in the art that such equivalent constructions do not depart from the teachings of the disclosure as set forth in the appended claims. The novel features, which are believed to be characteristic of the disclosure, both as to its organization and method of operation, together with further objects and advantages, will be better understood from the following description when considered in connection with the accompanying figures. It is to be expressly understood, however, that each of the figures is provided for the purpose of illustration and description only and is not intended as a definition of the limits of the present disclosure.

In an aspect of the disclosure, a method, a computer readable medium, and apparatus for operating a computational network are provided. The apparatus includes a memory and at least one processor coupled to the memory. The at least one processor may be configured to identify each object of a set of objects included in a first location, and the set of objects may include at least one IoT device and at least one other object. The at least one processor may be configured to determine a first set of attributes for the at least one IoT device, and the first set of attributes may indicate a first spatial relationship between the at least one IoT device and the at least one other object. The at least one processor may be configured to store registration information associated with the at least one IoT device, and the registration information may include a first identifier associated with the at least one IoT device and may include the first set of attributes for the at least one IoT device. The at least one processor may be configured to obtain an input. The at least one processor may be configured to determine whether the input corresponds to the at least one IoT device based on the registration information associated with the at least one IoT device. The at least one processor may be configured to control the at least one IoT device when the input corresponds to the at least one IoT device.

Additional features and advantages of the disclosure will be described below. It should be appreciated by those skilled in the art that this disclosure may be readily utilized as a basis for modifying or designing other structures for carrying out the same purposes of the present disclosure. It should also be realized by those skilled in the art that such equivalent constructions do not depart from the teachings of the disclosure as set forth in the appended claims. The novel features, which are believed to be characteristic of the disclosure, both as to its organization and method of operation, together with further objects and advantages, will be better understood from the following description when considered in connection with the accompanying figures. It is to be expressly understood, however, that each of the figures is provided for the purpose of illustration and description only and is not intended as a definition of the limits of the present disclosure.

BRIEF DESCRIPTION OF THE DRAWINGS

The features, nature, and advantages of the present disclosure will become more apparent from the detailed description set forth below when taken in conjunction with the drawings in which like reference characters identify correspondingly throughout.

FIG. **1** illustrates an example implementation of designing a neural network using a system-on-a-chip (SOC), including a general-purpose processor, in accordance with certain aspects of the present disclosure.

FIG. **2** is a block diagram illustrating various Internet-of-Things (IoT) devices referenced on a visual display associated with an agent, in accordance with aspects of the present disclosure.

FIG. **3** is a block diagram illustrating a location that includes one or more IoT devices that are spatially related to one or more objects present at a location, in accordance with aspects of the present disclosure.

FIG. **4** is a call flow diagram illustrating a method of discovering and controlling IoT devices, in accordance with aspects of the present disclosure.

FIG. **5** is a call flow diagram illustrating an example of one method of registering and referencing IoT devices, in accordance with aspects of the present disclosure.

FIG. **6** is a flow diagram illustrating a method of discovering and controlling at least one IoT device, in accordance with aspects of the present disclosure.

FIG. **7** is a flow diagram illustrating a method of discovering objects in a location, in accordance with aspects of the present disclosure.

FIG. **8** is a flow diagram illustrating a method of determining whether an input corresponds with at least one IoT device, in accordance with aspects of the present disclosure.

DETAILED DESCRIPTION

The detailed description set forth below, in connection with the appended drawings, is intended as a description of various configurations and is not intended to represent the only configurations in which the concepts described herein may be practiced. The detailed description includes specific details for the purpose of providing a thorough understanding of the various concepts. However, it will be apparent to those skilled in the art that these concepts may be practiced without these specific details. In some instances, well-known structures and components are shown in block diagram form in order to avoid obscuring such concepts.

Based on the teachings, one skilled in the art should appreciate that the scope of the disclosure is intended to cover any aspect of the disclosure, whether implemented independently of or combined with any other aspect of the disclosure. For example, an apparatus may be implemented or a method may be practiced using any number of the aspects set forth. In addition, the scope of the disclosure is intended to cover such an apparatus or method practiced using other structure, functionality, or structure and functionality in addition to or other than the various aspects of the disclosure set forth. It should be understood that any aspect of the disclosure disclosed may be embodied by one or more elements of a claim.

The word "exemplary" is used herein to mean "serving as an example, instance, or illustration." Any aspect described herein as "exemplary" is not necessarily to be construed as preferred or advantageous over other aspects.

Although particular aspects are described herein, many variations and permutations of these aspects fall within the scope of the disclosure. Although some benefits and advantages are mentioned, the scope of the disclosure is not intended to be limited to particular benefits, uses or objectives. Rather, aspects of the disclosure are intended to be broadly applicable to different technologies, system configurations, networks and protocols, some of which are illustrated by way of example in the figures and in the following description of the preferred aspects. The detailed description and drawings are merely illustrative of the disclosure rather than limiting, the scope of the disclosure being defined by the appended claims and equivalents thereof.

The aspects described herein may be practiced at least partially by one or more neural networks, machine-learning models, artificial intelligence systems, reinforcement learning systems, and/or other similar computing system. Such a system may be referred to in the present disclosure as an "agent" or "smart assistant." It will be appreciated that these terms are not intended to be limiting, and are intended to be illustrative. For example, an "agent," as used herein may refer to a local system and/or interconnected system, such as one or more local sensors coupled with one or more processors that are remotely disposed to the sensor (e.g., cloud computing).

The present disclosure may provide an approach to registering and referencing one or more Internet-of-Things (IoT) devices. Registering an IoT device may include storing information associated with a device in an agent. For example, such information may include a unique identifier associated with an IoT device. In addition, registering an IoT device include identifying a communication link between the agent and the IoT device, e.g., so that the agent may communicate with IoT device. For example, an agent may obtain one or more images of a first location (e.g., a room). The agent may identify one or more objects within that first location. The agent may identify one or more of those objects that are IoT devices that the agent is operable to control. The agent may construct a spatial mapping that indicates the locations of each of the objects, e.g., relative to one another. In one aspect, the spatial mapping may be from a frame of reference.

Thereafter, the agent may be configured to receive input from a user (e.g., natural language input). The agent may identify, from the input, a set of attributes that describes one of the IoT devices and a command indicating how the IoT device is to be controlled. The agent may identify the IoT device based on the input set of attributes indicating a spatial relationship of the IoT device relative to one or more of the other objects in the first location. For example, the agent may identify the IoT device having a spatial relationship to one or more objects in the first location that matches the input describing a spatial relationship of the IoT device observed by the user. The agent may then control the identified IoT device in a manner that is consistent with the input command.

FIG. **1** illustrates an example implementation of the aforementioned registration and reference to IoT devices using a system-on-a-chip (SOC) **100**, which may include a general-purpose processor (CPU) or multi-core general-purpose processors (CPUs) **102** in accordance with certain aspects of the present disclosure. Variables (e.g., neural signals and synaptic weights), system parameters associated with a computational device (e.g., neural network with weights), delays, frequency bin information, and task information may be stored in a memory block associated with at least one Neural Processing Unit (NPU) **108**, in a memory block associated with a CPU **102**, in a memory block associated with a graphics processing unit (GPU) **104**, in a memory block associated with a digital signal processor (DSP) **106**, in a dedicated memory block **118**, or may be distributed across multiple blocks. Instructions executed at the general-purpose processor **102** may be loaded from a program memory associated with the CPU **102** or may be loaded from a dedicated memory block **118**.

The SOC **100** may also include additional processing blocks tailored to specific functions, a connectivity block **110**, which may include fourth generation long term evolution (4G LTE) connectivity, unlicensed Wi-Fi connectivity, USB connectivity, Bluetooth connectivity, and the like, and a multimedia processor **112** that may, for example, detect and recognize gestures. In one implementation, the NPU is implemented in the CPU, DSP, and/or GPU—e.g., one or more neural-processing functions may be performed by the CPU, DSP, and/or GPU. The SOC **100** may also include a sensor processor **114**, image signal processors (ISPs), and/or navigation unit **120**, which may include a global positioning system.

The SOC **100** may be based on an ARM instruction set. In an aspect of the present disclosure, the instructions loaded into the general-purpose processor **102** may include code to identify each object of a set of objects included in a first location, and the set of objects may include at least one IoT device and at least one other object. The instructions may include code to determine a first set of attributes for the at least one IoT device, and the first set of attributes may indicate a first spatial relationship between the at least one

IoT device and the at least one other object. The instructions may include code to store registration information associated with the at least one IoT device, and the registration information may include a first identifier associated with the at least one IoT device and may include the first set of attributes for the at least one IoT device. The instructions may include code to obtain an input. The instructions may include code to determine whether the input corresponds to the at least one IoT device based on the registration information associated with the at least one IoT device. The instructions may include code to control the at least one IoT device when the input corresponds to the at least one IoT device.

Deep learning architectures may perform an object recognition task by learning to represent inputs at successively higher levels of abstraction in each layer, thereby building up a useful feature representation of the input data. In this way, deep learning addresses a major bottleneck of traditional machine learning. Prior to the advent of deep learning, a machine learning approach to an object recognition problem may have relied heavily on human engineered features, perhaps in combination with a shallow classifier. A shallow classifier may be a two-class linear classifier, for example, in which a weighted sum of the feature vector components may be compared with a threshold to predict to which class the input belongs. Human engineered features may be templates or kernels tailored to a specific problem domain by engineers with domain expertise. Deep learning architectures, in contrast, may learn to represent features that are similar to what a human engineer might design, but through training. Furthermore, a deep network may learn to represent and recognize new types of features that a human might not have considered.

A deep learning architecture may learn a hierarchy of features. If presented with visual data, for example, the first layer may learn to recognize relatively simple features, such as edges, in the input stream. In another example, if presented with auditory data, the first layer may learn to recognize spectral power in specific frequencies. The second layer, taking the output of the first layer as input, may learn to recognize combinations of features, such as simple shapes for visual data or combinations of sounds for auditory data. For instance, higher layers may learn to represent complex shapes in visual data or words in auditory data. Still higher layers may learn to recognize common visual objects or spoken phrases.

Deep learning architectures may perform especially well when applied to problems that have a natural hierarchical structure. For example, the classification of motorized vehicles may benefit from first learning to recognize wheels, windshields, and other features. These features may be combined at higher layers in different ways to recognize cars, trucks, and airplanes.

Neural networks may be designed with a variety of connectivity patterns. In feed-forward networks, information is passed from lower to higher layers, with each neuron in a given layer communicating to neurons in higher layers. A hierarchical representation may be built up in successive layers of a feed-forward network, as described above. Neural networks may also have recurrent or feedback (also called top-down) connections. In a recurrent connection, the output from a neuron in a given layer may be communicated to another neuron in the same layer. A recurrent architecture may be helpful in recognizing patterns that span more than one of the input data chunks that are delivered to the neural network in a sequence. A connection from a neuron in a given layer to a neuron in a lower layer is called a feedback (or top-down) connection. A network with many feedback connections may be helpful when the recognition of a high-level concept may aid in discriminating the particular low-level features of an input.

Across various locations (e.g., homes, workplaces, etc.), IoT devices are increasingly ubiquitous. In some locations, various IoT devices may be communicatively coupled with a smart assistant or other hub that allows interaction with the various IoT devices. For example, a user may control a IoT device in the user's home using a smart assistant.

In order to refer to an IoT device, the IoT device may be referenced by an identifier (e.g., name), such as a name of the IoT device. However, remembering the identifier of the IoT device, e.g., when issuing a voice command, may be cumbersome and frustrate the user. For example, IoT devices are frequently associated with ad-hoc and/or non-intuitive identifiers or names, which may frustrate the user experience.

In view of the foregoing, a needed exists for an intuitive way to refer to IoT devices without having to necessarily remember specific identifiers for the IoT devices. Rather, each IoT device may be referenced in natural manner that improves user experience. For example, the present disclosure may present an intuitive way to reference IoT devices using voice commands in an environment with a smart assistant or other agent, e.g., by leveraging vision and other sensory modalities. Accordingly, a user can issue commands to an IoT device without knowing the exact identifier assigned to that IoT device.

FIG. **2** illustrates a block diagram of a plurality of IoT devices that are referenced on a visual display **200** associated with an agent. For example, the visual display **200** may present a visual reference to a plurality of IoT devices that may be controlled through the agent. Illustratively, the agent may receive input from a user through the visual display (e.g., touchscreen) in order to control one or more IoT devices, such as one or more light fixtures disposed in various locations. The agent may control the one or more light fixtures in a manner that is consistent with input received through the visual display **200**. However, this approach may limit the scope of the agent. That is, the one or more IoT devices referenced on the visual display **200** may only be controlled by the agent through the input received through the visual display. The visual display **200** illustrates one example of an approach to receiving input, and the agent may receive input through one or more other approaches, e.g., including textual input and/or speech input (e.g., natural language input).

In aspects, the agent may include one or more different mechanisms that allow the agent to receive various input from different sources (e.g., one or more microphones). In order to intelligently control the one or more IoT devices, the agent may identify (e.g., learn) one or more attributes of the one or more IoT devices. When the agent receives input, the agent may intelligently match one or more attributes (e.g., spatial attributes) to one or more attributes of an IoT device based on a spatial mapping of a location. Further based on the input, the agent may then control the IoT device matching the set of input attributes, as described herein.

FIG. **3** is a block diagram illustrating a location **300** that includes a set of objects, in accordance with various aspects of the present disclosure. FIG. **3** illustrates an agent **302**. The agent **302** may include one or more neural networks, machine-learning models, artificial intelligence systems, reinforcement learning systems, word embedding models, natural language processing (NLP) models, and/or other similar computing systems. In one aspect, the agent **302** may be included in a virtual assistant, an intelligent personal assistant, and/or another computing agent. With references to FIG. **1**, the agent **302** may include and/or may be communicatively coupled with the SoC **100**.

While FIG. **3** illustrates the agent **302** as disposed in the location **300**, aspects of the present invention may be practiced when the agent **302** is absent from the location **300**. For example, the agent **302** may be located in another room that is different from the location **300**. In another aspect, the agent **302** may be communicatively coupled with a sensor (e.g., a microphone and/or camera) that is located in the location **300**, while the agent **302** is remotely located (e.g., in the cloud or other remote server).

The location **300** may include a set of objects **310***a-e*, **312***a-k*. The set of objects **310***a-e*, **312***a-k* may include a set of IoT devices **310***a-e*. By way of example, the set of IoT devices **310***a-e* may include a television **310***a*, a fireplace **310***b* (e.g., electronic fireplace), a first light **310***c* (e.g., a floor lamp), a second light **310***d* (e.g., a foyer light), and a third light **310***e* (e.g., a desk light). The set of IoT devices **310***a-e* may be referenced by an individual using natural language, e.g., "turn on the floor lamp," "turn on the foyer light," and/or "turn on the desk light." The present disclosure comprehends any number of IoT devices, such as a faucet, refrigerator, oven, stove, media center, speaker system, gaming console, coffee machine, blender, microwave, thermostat, security system, camera, detector (e.g., smoke and/or carbon monoxide detector), sensor, or essentially any other device capable of communicating though a network (e.g., wireless local area network (WLAN), WiFi, etc.), such as the Internet. In an aspect, the agent **302** may be communicatively coupled with the IoT devices **310***a-e*, e.g., through a network.

In one aspect, the agent **302** may register or store information associated with a respective identifier for each IoT device **310***a-e*. The agent **302** may refer to a respective one of the IoT devices **310***a-e* via the respective identifier. For example, when the agent **302** issues a command to the television **310***a*, the agent **302** may send a message over a network, and the message may include a respective identifier that is associated with the television **310***a* and indicates that the command is intended for the television **310***a*.

The set of objects **310***a-e*, **312***a-k* may further include a set of non-IoT objects **312***a-k*. By way of example, the set of non-IoT objects **312***a-k* may include a first painting **312***a*, a second painting **312***b*, a first couch **312***c*, a window **312***d*, a second couch **312***e*, a vase with flowers **312***f*, a coffee table **312***g*, a first chair **312***h*, a second chair **312***i*, a set of pots **312***j*, and/or a first wall **312***k*.

FIG. **4** is a call flow diagram illustrating a method **400** of operating an agent, in accordance with various aspects. The agent **302** may determine **420** to discover one or more of the IoT devices **310***a-e* present in the location **300**. In one aspect, the agent **302** may determine **420** to discover the one or more IoT devices **310***a-e* by obtaining a prompt, such as a user input (e.g., via speech input, via a device that may communicate with the agent **302**, via the agent directly, etc.). In another aspect, the agent **302** may automatically determine **420** to discover the one or more IoT devices **310***a-e*.

Based on the determination **420** to discover the IoT devices **310***a-e*, the agent may perform **422** discovery of IoT devices **310***a-e* in order to determine the IoT devices **310***a-e* that are available at the location **300**. For example, the agent **302** and the IoT devices **310***a-e* may be connected with one network **404***a* (e.g., WiFi network or another wireless network). The IoT devices **310***a-e* may send respective information (e.g., a respective identifier and/or other identifying information, such as attributes) over the first network **404***a*, and the agent **302** may obtain the respective identifiers for each of the IoT devices **310***a-e*. For example, the agent **302** may receive IoT device information **424** from the first light **310***c*, which may indicate an identifier associated with the first light **310***c*.

The agent **302** may store the respective identifiers for each of the IoT devices **310***a-e*. Further, if provided other information from one or more of the IoT devices **310***a-e*, the agent **302** may store this other information in association with the corresponding identifier. For example, the agent **302** may store the type of IoT device, the capabilities of the IoT device, and/or any other information that the agent **302** may obtain. In some aspects, the agent **302** may perform additional processing when storing respective identifiers and/or corresponding information for one or more of the IoT devices **310***a-e*. For example, the agent **302** may categorize one or more of the IoT devices **310***a-e*—e.g., the IoT devices **310***c-e* may be categorized as "lights."

In one aspect, during performance **422** of the discovery, the agent **302** may associate one or more respective visual attributes with each of the IoT devices **310***a-e*. For example, the agent **302** may obtain first image data **426**, which may represent the location **300** and include representations of each of the IoT devices **310***a-e*. The first image data **426** may be a still image or a moving image.

The agent **302** may store respective attributes corresponding to each of the IoT devices **310***a-e*, such as visual and/or spatial attributes. For example, the agent **302** may store a set of attributes corresponding to an identifier for one IoT device that indicates that an IoT device is a television **310***a*, and the set of attributes may indicate that the television **310***a* is above a fireplace **310***b*. In another example, the agent **302** may store a set of attributes corresponding to an identifier for one IoT device that indicates that an IoT device is a light **310***c*, and the set of attributes may indicate that the light **310***c* is to the left of the couch **312***e* and/or that the light **310***c* is blue in color. The agent **302** may categorize the sets of attributes corresponding to each of the IoT devices **310***a-e*, e.g., in order to categorize the lights **310***c-e* as a group with the capability of turning on/off a light.

In one aspect of the performance **422** of discovery, the agent **302** may obtain second image data **428** (e.g., a still image or moving image) that represents the location **300** including the IoT devices **310***a-e*. For example, the agent **302** may obtain the first image data **426** and wait a time period (e.g., predetermined time period) before obtaining the second image data **428**. In one aspect, the agent **302** may obtain the second image data **428** based on a change to a state of at least one of the IoT devices **310***a-e*. For example, the agent **302** may obtain the second image data **428** responsive to a message from the first light **310***c* indicating that the first light **310***c* has changed state (e.g., from an "off" state to an "on" state, or vice versa). In another aspect, the agent **302** may cause the change of state to the at least one of the IoT devices **310***a-e*, e.g., by sending a command to the first light **310***c* that includes an identifier associated with the first light **310***c* and instructs the first light **310***c* to change state (e.g., power on). The agent **302** may obtain the second image data **428** based on causing the state change. For example, the agent **302** may issue a command to the first light **310***c* indicating that the first light **310***c* is to change state (e.g., from an "off" state to an "on" state, or vice versa).

In an aspect, the agent **302** may compare the first image data **426** to the second image data **428** in order to detect one or more differences. For example, the agent **302** may determine that the first light **310***c* is now in an "on" state based on the difference between the first image data **426** (representing the first light **310***c* in an "off" state) and the second image data **428** (representing the first light **310***c* in an "on" state). The agent **302** may determine that an identifier of the first light **310***c* (e.g., included in a command to change the state of the first light **310***c*) corresponds to the representation of the first light **310***c* in the first image data **426** and/or the second image data **428**. That is, the agent **302** may compare the second image data **428** to the first image data **426** in order to identify a difference between the second image data **428** and the first image data **426**, and to identify the first light **310***c* (e.g., associated with an identifier) that corresponds to the IoT device represented with the identified difference (e.g., the first light **310***c* is powered off in the first image data **426** but powered on in the second image data **428** may be identified).

Based on the identified differences, the agent **302** may determine correspondence between a detected object and an IoT device. For example, the agent **302** may identify the first light **310***c* from the first image data **426**. Thereafter, the agent **302** may detect a state change (e.g., powering on) of the first light **310***c*. The agent **302** may compare the first image data **426** to second image data **428** in order to detect that an object identified as a light experienced a state change and, therefore, is the first light **310***c*. In one aspect, the agent **302** may identify a first identifier that is associated with the first light **310***c* and the agent **302** may register or store information indicating a correspondence between the first light **310***c* represented in the location **300** and the first identifier (e.g., the first identifier corresponding to the first light **310***c* may be used to communicate with (e.g., control) the first light **310***c*).

In one aspect, the agent **302** may store information that associates the visual representation of the first light **310***c* (e.g., in the first image data **426** and/or second image data **428**) with the first identifier, such as the set of visual and/or spatial attributes/relationships (e.g., a position of the first light **310***c* in the location **300**, a position of the first light **310***c* relative to one or more other IoT devices **310***a-b*, **310***d-e* and/or relative to one or more objects **312***a-k*, a color of the first light **310***c*, relative size of the first light **310***c*, etc.). Accordingly, the agent **302** may be configured to discover each IoT device of the set of IoT devices **310***a-e* over time as each IoT device of the set of IoT devices **310***a-e* experiences a respective state change.

In one aspect, the agent **302** may obtain the first image data **426** and/or the second image data **428** via an IoT device that is a camera communicatively coupled with the agent **302**. For example, the agent **302** may be communicatively coupled with the camera over a second network **404***b*, which may be a wired or wireless network (e.g., Bluetooth or other personal area network (PAN), WiFi network, etc.) (n.b., the first network **404***a* may be the same network as the second network **404***b*). The agent **302** may automatically obtain the first image data **426** and/or the second image data **428**—e.g., the agent **302** may automatically issue a command over the second network **404***b* to the camera to capture the second image data **428** based on a state change to one of the IoT devices **310***a-e*.

In another aspect, the agent **302** may obtain the first image data **426** and/or the second image data **428** based on user input. For example, the agent **302** may communicate over the second network **404***b* with a personal device (e.g., smart phone, tablet computer, etc.) of the user and/or one of the IoT devices **310***a-e* having the capability of outputting a prompt (e.g., the television **310***a* may output an audio prompt or visual prompt). The agent **302** may send a message over the second network **404***b* to the personal device prompting the user to capture image data representing the location **300**, and the personal device may send the image data to the agent **302** over the first network **404***a*. The agent **302** may send the message to the personal device based on a state change to one of the IoT devices **310***a-e*, e.g., prompting the user to capture the second image data **428** so that the agent **302** may identify differences between the first image data **426** and the second image data **428**. In another example, the agent **302** may output a prompt to capture the first and/or second image data **426**, **428**, such as an audio prompt, from a speaker communicatively coupled with the agent **302** (e.g., an IoT speaker, a speaker integrated in the housing of the agent **302**).

In one aspect, the agent **302** may systematically cause state changes to a plurality of IoT devices from which the agent **302** has obtained information (e.g., respective identifiers of each of the IoT devices **310***a-e*, which may be obtained via respective messages communicated over the first network **404***a*). For example, the agent **302** may iterate through a list of each of the IoT device from which the agent **302** has obtained information (e.g., the agent **302** may receive respective identifiers from each of the IoT devices **310***a-e* over the first network **404***a*), obtaining a new image after each iteration (e.g., the second image data **428**). Therefore, the agent **302** may discover and catalog each IoT device with which the agent **302** may communicate, such as by cataloging a respective location associated with each of the IoT devices **310***a-e*.

When at least one of the IoT devices **310***a-e* is discovered by the agent **302**, the agent **302** may monitor for commands directed to one of the IoT devices **310***a-e*. In one aspect, the agent **302** may receive a command **430** via a microphone. The command **430** may be a speech input, such as a natural language input. In another aspect, the command **430** may be written or obtained via a message, such as a written command or other message obtained from a personal device of a user and communicated to the agent **302** over the first network **404***a*.

The agent **302** may process **432** the command **430** to determine which of the IoT devices **310***a-e* is referenced by the command **430**. The agent **302** may process **432** to the command **430** to determine an input set of attributes describing one of the IoT devices **310***a-e*. For example, the command **430** may indicate "turn on the light to the left of the couch." The agent **302** may process the command **430** to identify an input set of attributes indicating a type of IoT device (e.g., a light) and a relative position of the IoT device (e.g., to the left of the couch). The agent **302** may compare the input set of attributes to stored sets of attributes in order to determine that the command **430** references the first light **310***c*. For example, the agent **302** may determine that the type of device is a light, and the agent **302** may retrieve sets of attributes for the category light. The agent **302** may determine that the type of device that is a light and is to the left of the couch corresponds to the first light **310***c*. Further, the agent **302** may process **432** the command **430** to determine that the first light **310***c* is to be controlled so that the state of the first light **310***c* is turned to "on." Accordingly, the agent **302** may send an instruction **434** over the first network **404***a* to the first light **310***c*, and the instruction **434** may cause the first light **310***c* to change state to "on." The agent **302** may identify and control other IoT devices **310***a-b, d-e* in an approach similar to that described herein with respect to the first light **310***c*.

In an aspect, the agent **302** may periodically "refresh" all or a portion of the information corresponding to one or more of the IoT devices **310***a-e* with which the agent **302** may communicate (e.g., the agent **302** may update one or more sets of attributes corresponding to one or more of the IoT devices **310***a-e*). That is, the agent **302** may be configured to determine **420** to discover the IoT devices **310***a-e* according to a predetermined time period. For example, the agent **302** may determine **420** to discover the IoT devices **310***a-e* after every twenty-four hour time period, after every week, and/or after another time period. In one aspect, the agent **302** may determine **420** to discover IoT devices **310***a-e* based on an event. For example, the agent **302** may be unable to decode a message received from an IoT device over the first network **404***a*—e.g., the command **430** may indicate "turn on the light over the red sofa" when the red sofa is newly placed in the location **300** and the agent **302** has yet to identify the red sofa in the location **300**. In further examples of events that may trigger the "refresh" by the agent **302**, the agent **302** may be unable to identify an IoT device from which a message is received over the first network **404***a*, the agent **302** may detect that an IoT device has moved based on the first image data **426** and/or the second image data **428**, the agent **302** may receive a message over the first network **404***a* from an IoT device that the agent **302** has not yet registered, or another similar event.

FIG. **5** is a call flow diagram illustrating a method **500** of operating an agent, in accordance with various aspects. The method **500** illustrates one aspect of discovery and controlling IoT devices. For example, the method **500** may be a specific aspect of the method **400**. Accordingly, the agent **302'** may be an aspect of the agent **302** of FIGS. **3** and **4**. The IoT device **310'** may be an aspect of one of the IoT devices **310***a-e* illustrated in FIGS. **3** and **4**, such as the television **310***a*, the fireplace **310***b*, one of the lights **310***c-e*, or another IoT device.

In various aspects, the agent **302'** may include and/or may be communicatively coupled with a camera **506** that is configured to capture image data (e.g., static images, video, etc.). Further, the agent **302'** may include and/or may be communicatively coupled with a microphone **508**. In one aspect, the camera **506** and/or the microphone **508** may be located on a personal device (e.g., smartphone) of a user, a smart speaker, and/or another virtual assistant.

In various aspects, the agent **302'** may be configured to obtain first image data **520** representing the location **300** that includes the set of IoT devices **310***a-e* (**310'**) and the set of non-IoT objects **312***a-k*. For example, the agent **302** may include and/or may be communicatively coupled with one or more cameras (e.g., Internet Protocol (IP) cameras, the camera **506**, etc.). In one aspect, the agent **302'** may obtain the first image data **520** from a user. For example, the agent **302'** may receive a wireless transmission from a smartphone or other personal device of the user, and the wireless transmission may include the first image data **520**. In various aspect, the first image data **520** may be a static image at least partially representing the location **300**, a video recording at least partially representing the location **300**, a moving image at least partially representing the location **300**, or another type of data that represents a visual depiction of the location **300**.

In various aspects, the agent **302'** may identify **522** the set of objects **310***a-e* (**310'**), **312***a-k* in the location **300**. The agent **302'** may include a DNN and/or other machine-learning model. For example, agent **302'** may include one or more reinforcement-learning models, a CNN, an RNN, or another object-detection system. In one aspect, the agent **302'** may include one or more neural networks that implement a Single Shot Multibox Detector (SSD) and/or You Only Look Once (YOLO) for object detection (e.g., real-time object detection). In one aspect, the agent **302'** may identify each object of the set of objects **310***a-e* (**310'**), **312***a-k* in the location **300** by processing the first image data **520** using a DNN or other model/neural network. The agent **302'** may obtain the output of the processing in which each object of the set of objects **310***a-e* (**310'**), **312***a-k* is identified.

In one aspect, one or more of the IoT devices **310***a-e* may send (e.g., broadcast) information identifying the one or more IoT devices **310***a-e*. For example, the first light **310***c* may broadcast an identifier and/or other information associated with the first light **310***c* (e.g., information indicating capabilities, type of device, information indicating a change in state of the first light **310***c*, etc.).

In one aspect, the agent **302'** may detect **524** a state change to a first IoT device **310'**. For example, the agent **302'** may detect that the first IoT device **310'** is powered on or that the first IoT device **310'** has received information (e.g., via input from a user, via information transmitted by the first IoT device **310'** to the agent **302'**, etc.) associated with the first IoT device **310'**. For example, the received information may indicate that the first IoT device **310'** is now in a powered-on state (e.g., "the first light is now on" received via user input, via information transmitted by the first light **310***c* indicating that the first light **310***c* is now on, etc.). The agent **302'** may obtain second image data **526** representing the location **300**. In an aspect, the agent **302'** may compare the first image data **520** to the second image data **526** in order to detect one or more differences (e.g., a light that is powered on, a faucet that is now running water, etc.). For example, the agent **302'** may determine that the first light **310***c* is now on based on the difference between the first image data **520** and the second image data **526**, and the agent **302'** may determine that the received information corresponds to the first light **310***c*.

In one aspect, the agent **302'** may obtain the second image data **526** based on the detected state change. For example, the agent **302'** may cause a camera to capture an image of the location **300** in order to compare that image to the first image data **520**. In one aspect, the agent **302'** may be configured to cause a state change to an IoT device **310'**, e.g., after the first image data **520** is processed and before the second image data **526** is processed. For example, agent **302'** may receive a communication from the IoT device **310'** indicating information associated with the IoT device **310'**, such as an identifier of the IoT device **310'**, a type of the IoT device **310'**, etc. The agent **302'** may capture the second image data **526**, and then the agent **302'** may send a command to the IoT device **310'** causing the state change to the IoT device **310'** (e.g., a command to cause the IoT device **310'** to power on). The agent **302'** may then capture the second image data **526**. The agent **302'** may compare the second image data **526** to the first image data **520** in order to identify a difference between the second image data **526** and the first image data **520**, and to identify the IoT device **310'** that corresponds to the identified difference (e.g., a light **310***c* that is powered off in the first image data **520** but powered on in the second image data **526** may be identified). Based on identifying the IoT device **310'**, the agent **302'** may store a correlation between the information associated with the IoT device **310'** (e.g., an identifier associated with the IoT device **310'**) and one or more attributes of the IoT device **310'**, which may be derived from the first image data **520** and/or the second image data **526** (e.g., a position of the IoT device **310'** in a room, a color of the IoT device **310'**, relative size of the IoT device **310'**, etc.).

In one aspect, the agent **302'** may systematically cause state changes to a plurality of IoT devices (including the IoT device **310'**) from which the agent **302'** has obtained information (e.g., respective identifiers of each of the IoT devices). For example, the agent **302'** may iterate through a list of each of the IoT device from which the agent **302'** has obtained information, capturing a new image after each iteration (e.g., the second image data **526**). Therefore, the agent **302'** may catalog each IoT device with which the agent **302'** may communicate.

Based on the detected differences, the agent **302'** may determine correspondence between a detected object and an IoT device. For example, the agent **302'** may identify the first IoT device **310'** as a television **310***a* from the first image data **520**. Thereafter, the agent **302'** may detect a state change (e.g., powering on) of the first IoT device **310'**. The agent **302'** may compare the first image data **520** to second image data **526** in order to detect that object identified as the television experienced the state change and, therefore, is the first IoT device **310'**. Further, the agent **302'** may receive information (e.g., via input from a user) indicating that the television **310***a* has changed state (e.g., been powered on). The agent **302'** may compare the first image data **520** to the second image data **526** to determine that the television **310***a* has changed state between the first image data **520** and the second image data **526**, and therefore, the television **310***a* is the first IoT device **310'** that is referenced (e.g., via user input).

The agent **302'** may identify a first identifier that is associated with the first IoT device **310'** and the agent **302'** may register or store information indicating a correspondence between the first IoT device **310'** present in the location **300** (and represented in the first image data **520** and/or second image data **526**) and a first identifier that may be used to communicate with (e.g., control) the first IoT device **310'**. For example, the agent **302'** may store information that associates the visual representation of the first IoT device **310'** (e.g., in the first image data **520** and/or second image data **526**) with the first identifier. Accordingly, the agent **302'** may be configured to automatically discovery each IoT device of the set of IoT devices **310***a-e* (**310'**) over time as each IoT device of the set of IoT devices **310***a-e* (**310'**) experiences a respective state change.

In one aspect, the agent **302'** may receive input from a user in order to identify correspondence between the visual representation of first IoT device **310'** (e.g., represented in the first image data **520** and/or second image data **526**) and the first identifier associated with the first IoT device **310'**. For example, the agent **302'** may receive a first input associated with the first IoT device **310'** following the state change to the first IoT device **310'**. In one aspect, the agent **302'** may prompt the user for the first input in order to identify the first IoT device **310'** after the state change so that the agent **302'** may identify the first IoT device **310'** in the first image data **520** and/or second image data **526**.

In one aspect, the agent **302'** may receive input from the first IoT device **310'** in order to identify correspondence between the visual representation of first IoT device **310'** (e.g., represented in the first image data **520** and/or second image data **526**) and the first identifier associated with the first IoT device **310'**. For example, the agent **302'** may receive a first input **525** associated with the first IoT device **310'** following the state change to the first IoT device **310'**. For example, the agent **302'** may receive a first input **525** from the first IoT device **310'** indicating that the first IoT device **310'** has transitioned to a powered-on state, and the agent **302'** may identify the first IoT device **310'** in the first image data **520** and/or second image data **526**.

Accordingly, the agent **302'** may identify the first IoT device **310'** based on the received first input. In one aspect, the agent **302'** may receive the first input via tactile or visual input. For example, the agent **302'** may detect that the user is touching or pointing to the first IoT device **310'** (e.g., based on image data captured through the camera **506**). In another aspect, the agent **302'** may receive the first input as speech input. For example, the agent **302'** may receive (e.g., through the microphone **508** and/or directly through the agent **302'**) a description of the first IoT device **310'**, such as a natural language input describing the first IoT device **310'**. In another aspect, the agent **302'** may receive the first input as text input, such as directly through the agent **302'** and/or through a smartphone or other personal device of the user).

Based on the first input, the agent **302'** may correlate the first IoT device **310'** indicated by the first input with a first identifier associated with the first IoT device **310'**. For example, the agent **302'** may store information that associates the visual representation of the first IoT device **310'** (e.g., in the first image data **520** and/or second image data **526**) with the first identifier. Accordingly, the agent **302'** may register or store information indicating a correspondence between the first IoT device **310'** present in the location **300** (and represented in the first image data **520** and/or second image data **526**) and a first identifier that may be used to communicate with (e.g., control) the first IoT device **310'**.

In one aspect, the agent **302'** may correlate the first IoT device **310'** with a first identifier based on Simultaneous Localization and Mapping (SLAM). For example, a user may walk around the location **300** (e.g., with a smartphone) and describe the IoT devices **310***a-e*. The microphone **508** may receive the user's speech and provide that speech to the agent **302'**. The agent **302'** may obtain the user's position (e.g., based on smartphone position, another sensor, and/or image data) and identify the IoT device of the IoT devices **310***a-e* to which the user is referring in the speech obtained from the microphone **508**. Accordingly, the agent **302'** may register or store information indicating a correspondence between the first IoT device **310'** present in the location **300** (and represented in the first image data **520** and/or second image data **526**) and a first identifier that may be used to communicate with (e.g., control) the first IoT device **310'**.

Based on the correspondence between the detected object and an IoT device, the agent **302'** may determine **528** a set of attributes for each IoT device **310***a-e* (**310'**). The set of attributes for each IoT device of the set of IoT devices **310***a-e* (**310'**) may indicate at least one spatial relationship between a respective IoT device of the set of IoT devices **310***a-e* (**310'**) and at least one other object of the set of objects **310***a-e* (**310'**), **312***a-k*.

Illustratively, the agent **302'** may determine **528** a first set of attributes for the first IoT device **310'**. The first set of attributes may indicate a spatial relationship between the first IoT device **310'** and at least one other object of the set of objects **310***a-e* (**310'**), **312***a-k*. For example, the first set of attributes may indicate that the first IoT device **310'** is a television **310***a* that is above a fireplace **310***b*. In another example, the first set of attributes may indicate that the first IoT device **310'** is the television **310***a* that is to the left of the light **310***c*. In another example, the first set of attributes may indicate that the first IoT device **310'** is the television **310***a* that is to the right of the pots **312***j*. In another example, the first set of attributes may indicate that the first IoT device **310'** is the television **310***a* that is behind the coffee table **312***g*.

The agent **302'** may determine **528** a set of attributes for each IoT device of the set of IoT devices **310***a-e* (**310'**). In one aspect, the agent **302** may construct a spatial mapping that indicates the respective locations of each object of the set of objects **310***a-e* (**310'**), **312***a-k* disposed through the location **300**. In one aspect, the spatial mapping may indicate coordinates, distances, and/or vectors of each object of the set of objects **310***a-e* (**310'**), **312***a-k*.

In one aspect, the agent **302'** may be configured to dynamically refer to and/or adjust the spatial mapping based on a frame of reference. For example, the agent **302'** may construct a spatial mapping based on the first image data **520** and/or second image data **526**. However, the agent **302'** may dynamically refer to and/or adjust the spatial mapping based on a frame of reference that is different from the frame(s) of reference captured in the first image data **520** and/or second image data **526**. The agent **302'** may determine one or more spatial attributes of the first IoT device **310'** based on the frame of reference. For example, the one or more spatial attributes of the first IoT device **310'** may be dynamically determined and/or updated based on the frame of reference.

In one aspect, the agent **302'** may determine the frame of reference based on information indicating a position of a smartphone of a user (e.g., through WiFi positioning, PAN positioning, such as Bluetooth positioning, or another approach). The agent **302'** may obtain (e.g., receive) information indicating the position of the smartphone, and the agent **302'** may dynamically refer to and/or update the spatial mapping based on a frame of reference that is consistent with the detected smartphone. In another example, the agent **302'** may receive image data (e.g., through the camera **506**) and identify a position of the user in the location **300**. Based on the position of the user, the agent **302'** may dynamically refer to and/or update the spatial mapping based on a frame of reference that is consistent with the position of the user.

In one aspect, the set of attributes for each of the IoT devices **310***a-e* (**310'**) may indicate other attributes in addition to the spatial attributes. For example, the first set of attributes for the first IoT device **310'** may include a classification associated with the first IoT device **310'**. A classification attribute may indicate a class or type of the first IoT device **310'**. For example, the classification attribute may indicate that the first IoT device **310'** is a television **310***a*, the classification attribute may indicate that the first IoT device **310'** is a fireplace **310***b*, the classification attribute may indicate that the first IoT device **310'** is a light **310***c*, etc.

In another example, the first set of attributes for the first IoT device **310'** may include a visual attribute associated with the first IoT device **310'**. A visual attribute may indicate one or more physical characteristics of the first IoT device **310'**. For example, a visual attribute may indicate that the first IoT device **310'** is a certain color (e.g., red, green, blue, etc.). In another example, a visual attribute may indicate that the first IoT device **310'** is of a specific or relative size (e.g., a "big" television). In another example, a visual attribute may indicate that the first IoT device **310'** includes one or more physical features (e.g., a light with a shade). In another example, a visual attribute may indicate that the first IoT device **310'** is of a shape.

In another example, the first set of attributes for the first IoT device **310'** may include a capability attribute associated with the first IoT device **310'**. A capability attribute may indicate one or more capabilities of the first IoT device **310'**. For example, a capability attribute may indicate one or more commands that the first IoT device **310'** is capable of executing or performing. An example of a capability attribute may be that the first IoT device **310'** is capable of powering on or off (e.g., when the first IoT device **310'** is a television **310***a* or a light **310***c*). Another example of a capability attribute may be that the first IoT device **310'** is capable of turning on or off a light (e.g., when the first IoT device **310'** is a light **310***c*). Another example, of a capability attribute may be that the first IoT device **310'** is capable of setting a baking temperature to 400 degrees (e.g., when the first IoT device **310'** is an oven). Another example of a capability attribute may be that the first IoT device **310'** is capable of turning on or off a stream of water (e.g., when the first IoT device **310'** is a faucet).

In one aspect, the agent **302'** may store **530** (e.g., register) each IoT device **310***a-e* (**310'**) in association with a respective set of attributes. For example, the agent **302'** may store registration information that includes the first identifier associated with the first IoT device **310'** and also include the first set of attributes for the first IoT device **310'**. Accordingly, the agent **302'** may register a respective identifier of a respective IoT device **310***a-e* (**310'**) in memory (e.g., local or remote) in association with a respective set of attributes. Therefore, the agent **302'** may identify a respective identifier of a respective IoT device **310***a-e* (**310'**) based on a respective set of attributes in order to communicate with that respective IoT device **310***a-e* (**310'**).

In various aspects, the agent **302'** may control operation of each IoT device **310***a-e* (**310'**) based on the registration information that includes a respective identifier associated with a respective IoT device **310***a-e* (**310'**) and also includes a respective set of attributes for the at least one IoT device. For example, the agent **302'** may obtain (e.g., receive) IoT-control input **532** that indicates an input set of attributes and also includes a command for an IoT device. The agent **302'** may compare the input set of attributes to each set of attributes stored indicated in respective registration information, and the agent **302'** may identify a registered first set of attributes that matches the input set of attributes. The agent **302'** may consider a registered first set of attributes as matching the input set of attributes when the registered first set of attributes is approximately similar (e.g., within a threshold margin of error) and/or most closely matches (e.g., respective to other registered sets of attributes) the input set of attributes.

The agent **302'** may then identify the respective identifier corresponding to the registered set of attributes that matches the input set of attributes. Based on the respective identifier, the agent **302'** may control operation of the respective one of the IoT devices **310***a-e* (**310'**) that corresponds to the respective identifier in accordance with the input command.

For example, the first IoT device **310'** may be the first light **310***c*. The agent **302'** may obtain (e.g., receive) IoT-control input **532** that indicates an input set of attributes for a "light" that is "to the left of the couch" and an input command to "adjust the brightness to be lower." Therefore, the input set of attributes may include a plurality of attributes, such as a spatial attribute, a classification attribute, a visual attribute, and/or a capability attribute.

The agent **302'** may be configured to match each input attribute of the input set of attributes to a respective corresponding attribute of a registered set of attributes. For example, the agent **302'** may match the input attribute "light" to a classification attribute of the first light **310***c* and may match the input attribute "to the left of the couch" to the spatial attribute indicating a relative position that is to the left of the couch **312***e* (e.g., from the user's perspective when the user is positioned in front of the couch **312***e*). The agent **302'** may identify the first identifier that corresponds to the first light **310***c*. The agent **302'** may then generate a message that indicates the input command (e.g., lower the brightness), and the agent **302'** may provide the generated message to the first light **310***c* in order to cause the first light **310***c* to lower the brightness.

In one aspect, the agent **302'** may obtain (e.g., receive) IoT-control input **532** as natural language input. For example, the microphone **508** may receive a natural language input from a user, and the agent **302'** may obtain the natural language input from the microphone **508**. The agent **302'** may detect an input set of attributes and a input control operation from the natural language input.

In one aspect, the agent **302'** may parse the natural language input using a DNN in order to identify the input set of attributes and the input control operation. In various aspects, the agent **302'** may parse the natural language input using an NLP model, word embedding, and/or another language modeling or feature-identification technique.

From the input set of attributes, the agent **302'** may identify an identifier of at least one IoT device. For example, the agent **302'** may compare each input attribute of the input set of attributes to each corresponding first attribute of the first set of attributes associated with the first IoT device **310'** (e.g., compare an input spatial attribute to a first spatial attribute of the first set of attributes, compare an input classification attribute to a first classification attribute of the first set of attributes, etc.). In one aspect, the agent **302'** may use a DNN in order to compare or classify features associated with the input set of attributes, and the agent **302'** may use feature comparison or classification of the DNN to compare or correspond to the first set of attributes. When the agent **302'** determines that the first set of attributes matches the input set of attributes, the agent **302'** may identify the first identifier associated with the first IoT device **310'** (e.g., the agent **302'** may store a mapping that indicates correspondence between the first set of attributes and the first identifier associated with the first IoT device **310'**).

The agent **302'** may then control operation of the first IoT device **310'** based on the identification of the first identifier and the input control operation. For example, the agent **302'** may identify an operation or function of the first IoT device **310'** that corresponds to the input control operation, such as powering on or off, changing channel, adjusting a lighting level, setting a temperature, etc.

Other various examples of input control operations include relative or contextual inputs. For example, the agent **302'** may obtain an IoT-control input **532** that indicates the light **310***c* is to be balanced with the natural light through the window **312***d* behind the light **310***c*. The agent **302'** may obtain (e.g., from an ambient-light sensor) a current lighting level, and the agent **302'** may determine the level to which the light **310***c* is to be adjusted in order to be consistent with the current lighting level. In another example, the agent **302'** may receive an IoT-control input **532** that indicates "turn on the light next to the couch on the left." The agent **302'** may identify the couch **312***e* in the right of the location **300** (e.g., based on a frame of reference), and the agent **302'** may then identify the light **310***c* next to the couch **312***e* on the right of the location **300**.

The agent **302'** may issue a command or instruction **534** to the first IoT device **310'** to perform the identified operation or function. For example, the agent **302'** may generate an instruction message **534** that includes the first identifier and the includes the command or instruction.

The agent **302'** may send the generated instruction message **534** over the network for reception by the first IoT device **310'**. The first IoT device **310'** may receive the instruction message **534**. Responsively, the first IoT device **310'** may determine that the instruction message **534** is intended for the first IoT device **310'** (e.g., by comparing the identifier of the first IoT device **310'** to the identifier indicated in the instruction message **534**). The first IoT device **310'** may execute or perform the instruction indicated by the instruction message **534**. For example, the first IoT device **310'** may power on, change channels, adjust a lighting level, adjust a temperature, turn off, adjust a volume, or essentially any other function of which an IoT device is capable.

FIG. **6** illustrates a method **600** of operating an agent in communication with at least one IoT device, in accordance with various aspects. The method may be practiced by an agent, such as the agent **302/302'**. One or more of the illustrated operations may be transposed, omitted, and/or contemporaneously performed. Operations illustrated with dashed lines may be optional.

Beginning with operation **702**, the agent may determine to identify a set of IoT devices. For example, the agent may obtain a prompt, such as a user input. The agent may determine to identify the set of IoT devices based on the prompt. In another aspect, the agent may determine to identify the set of IoT devices based on a time period. For example, the agent may periodically determine to identify the set of IoT devices after one day, after one week, and/or after another time period. In another aspect, the agent may determine to identify the set of IoT devices based on an event. For example, the agent may determine to identify the set of IoT devices when the agent is unable to decode a message received from an IoT device, when the agent receives a message from a new (e.g., unregistered) IoT device, when the agent detects an IoT device has moved (e.g., based on image data), and/or based on another event.

In the context of FIGS. **3-4**, the agent **302** may determine **420** to discover one or more of the IoT devices **310***a-e* present in the location **300**. In one aspect, the agent **302** may determine **420** to discover the one or more IoT devices **310***a-e* by obtaining a prompt, such as a user input (e.g., via speech input, via a device that may communicate with the agent **302**, via the agent directly, etc.). In another aspect, the agent **302** may automatically determine **420** to discover the one or more IoT devices **310***a-e*. In the example illustrated in FIG. **5**, the agent **302'** may determine that the agent **302'** is to identify **522** a set of objects, and the set of objects may include a set of IoT devices.

At operation **604**, the agent may receive, over a network information associated with at least one IoT device of the set of IoT devices. For example, the agent may receive a message from an IoT device over a WiFi network, and the message may indicate an identifier associated with the IoT device. The agent may store the information in order to identify the IoT device. In the context of FIGS. **3-4**, the agent **302** may receive the IoT device information **424** from the first light **310***c*, which may include an identifier associated with the first light **310***c*. In the example illustrated in FIG. **5**, the agent **302'** may receive information from the IoT device **310'**, and the received information may include an identifier associated with the IoT device **310'**.

At operation **606**, the agent may identify each object of a set of objects included in a first location. In an aspect, the set of objects may include at least one IoT device and at least one other object. For example, the agent may obtain first image data representing a location, and the agent may process the first image data using a neural network (e.g., a DNN). The neural network may process the first image data to generate at least one output, and the output may identify each object of the set of objects included in the first location represented by the first image data (e.g., the output may indicate a classification or category for each object of the set of objects, including the set of IoT devices). In the context of FIGS. **3-4**, the agent **302** may perform **422** discovery of each object of the set of objects **310***a-e*, **312***a-k* included in the location **300** represented in the first image data **426**. In the example illustrated in FIG. **5**, the agent **302'** may identify **522** objects included in the first image data **520** representing the location **300**.

At operation **608**, the agent may determine a first set of attributes for the at least one IoT device. In aspects, the first set of attributes may indicate visual and/or spatial attributes (e.g., relationship(s)) between the at least one IoT device and the at least one other object. In one aspect, the spatial relationship may be based on the identified frame of reference. In one aspect, the agent may construct a spatial mapping that represents that at least one IoT device relative to the at least one other object in the first location. The agent may further determine one or more other attributes of the at least one IoT device (e.g., a classification attribute, a visual attribute, a capability attribute, etc.).

In an aspect, the agent may determine the first set of attributes for the at least one IoT device based on image data (e.g., first image data and the second image data, moving image data, etc.). For example, the agent may detect a state change to the at least one IoT device, and the agent may identify the identifier of the at least one IoT device that underwent the state change. The agent may compare the first image data to the second image data to determine the at least one IoT device that is different between the first image data and the second image data after the state change, and the agent may infer that the identifier corresponds to the at least one IoT device that is different between the first image data and the second image data.

In another aspect, the agent may determine the first set of attributes based on the first input (e.g., user input) associated with the at least one IoT device. For example, the agent may detect the state change to the at least one IoT device, and the agent may identify the identifier of the at least one IoT device that underwent the state change. The agent may receive the first input describing the at least one IoT device (e.g., through a microphone or camera), e.g., after the state change, and the agent may infer that the identifier corresponds to the at least one IoT device that is described by the first input.

In the context of FIGS. **3-4**, the agent **302** may perform **422** discovery of IoT devices, including identifying a first set of attributes for the first light **310***c*. The first set of attributes may indicate visual and/or spatial relationship between the first light **310***c* and at least one other object of the set of objects (e.g., the IoT devices **310***a-b*, **310***d-e* and/or the non-IoT objects **312***a-k*). For example, the agent **302** may determine that a first set of attributes for the first light **310***c*, and the first set of attributes may indicate a classification attribute of "light" and a spatial relationship indicating to the left of the couch, in front of the window, etc. In the example illustrated in FIG. **5**, the agent **302'** may determine **528** attributes of the IoT device **310'**, and the first set of attributes may indicate a spatial relationship between the first IoT device **310'** and at least one other object of the set of objects **310***a-e*, **312***a-k*. For example, the agent **302/302'** may determine that a first set of attributes for the television **310***a*, and the first set of attributes may indicate a classification attribute of "television" and a spatial relationship indicating above the fireplace, on a rear wall, to the right of the pots, etc

At operation **610**, the agent may store registration information that includes the first identifier associated with the at least one IoT device and the first set of attributes. For example, the agent may store the first set of attributes, and the agent may store information indicating a correspondence between the first set of attributes and the first identifier for the at least one IoT device. In the context of FIGS. **3-4**, the agent **302** may perform **422** discovery of the IoT devices **310***a-e*, including storing registration information that includes a first identifier associated with the first light **310***c* and includes the first set of attributes for the first light **310***c*.

At operation **612**, the agent may obtain an input. In various aspects, the input may be a speech input (e.g., natural language input). For example, the agent may obtain (e.g., receive through a microphone) a natural language input, and the agent may parse the natural language input to identify an input set of attributes and an input control operation. In another aspect, the input may be received from a device (e.g., smartphone) communicatively coupled with the agent **302**, and the input may be provided by a user. In the context of FIGS. **3-4**, the agent **302** may obtain the command **430**. In the example illustrated in FIG. **5**, the agent **302'** may obtain the IoT-control input **532**.

At operation **614**, the agent may determine whether the input corresponds to the at least one IoT device based on the stored registration information associated with the at least one IoT device. For example, the agent may process the input (e.g., using a neural network, such as a DNN) in order to identify an input set of attributes, and the agent may correlate the input set of attributes with a stored set of attributes stored as the registration information associated with the at least one IoT device. The agent may at least partially match one or more of the input set of attributes with one or more of the stored set of attributes, and the agent may determine the identifier associated with the IoT device that is associated with the stored set of attributes that at least partially matches the input set of attributes. In an aspect, the input may indicate an input spatial relationship between the at least one IoT device and the at least one other object, and the determining whether the input corresponds to the at least one IoT device may be based on correspondence (e.g., at least partially matching) between the input spatial attribute and a first spatial attribute included in the set of attributes associated with the at least one IoT device.

In the context of FIGS. **3-4**, the agent **302** may process **432** the command **430** in order to identify an input set of attributes. The agent **302** may at least partially match the input set of attributes with a stored set of attributes associated with the first light **310***c* in order to determine that the command **430** is intended for the first light **310***c*. In the example illustrated in FIG. **5**, the agent **302'** may process the IoT-control input **532** in order to identify an input set of attributes. The agent **302** may at least partially match the input set of attributes with a stored set of attributes associated with the IoT device **310'** in order to determine that the IoT-control input **532** is intended for the IoT device **310'**.

At operation **616**, the agent may control operation of the at least one IoT device when the input corresponds to the at least one IoT device. For example, the agent may generate a message that includes the first identifier corresponding to the (at least partially) matching set of attributes and associated with the at least one IoT device. The agent may process the input to identify a command for the at least one IoT device. The agent may include, in the generated message, an instruction to perform an operation consistent with the identified command. The agent may send the message over a network to the at least one IoT device. In the context of FIGS. **3-4**, the agent **302** may control operation of the first light **310***c* by sending the instruction **434** to the first light **310***c* over the network **404***a*. In the example illustrated in FIG. **5**, the agent **302'** may control operation of the IoT device **310'** by sending the instruction message **534** to the IoT device **310'**.

With reference to FIG. **7**, a flowchart illustrates one method **700** that is one aspect of operation **606**, in which the agent may identify each object of a set of objects included in the first location. At operation **702**, the agent may obtain first image data representing a first location that includes a set of objects. In an aspect, the set of objects may include at least one IoT device and at least one other object (e.g., a stationary object or another IoT device). For example, the agent may request, from a camera, first image data that represents a first location that includes a set of objects. Based on the request, the agent may receive the first image data that represents the first location.

In the context of FIGS. **3-4**, the agent **302** may obtain first image data **426** representing the location **300** that includes the set of objects **310***a-e*, **312***a-k*. The set of objects may include the IoT devices **310***a-e* and the set of non-IoT objects **312***a-k*. In an aspect, the agent **302** may obtain the first image data **426** over a network **404***a* (e.g., via a camera that is communicatively coupled with the agent **302**). In the example illustrated in FIG. **5**, the agent **302'** may obtain first image data **520** representing the location **300** that includes the set of objects **310***a-e* (**310'**), **312***a-k*. The set of objects may include the IoT devices **310***a-e* (**310'**) and the set of non-IoT objects **312***a-k*. In an aspect, the agent **302'** may obtain the first image data **520** through the camera **506**.

At operation **704**, the agent may change a state of the at least one IoT device. For example, the agent may generate a command including an identifier associated with the at least one IoT device, and the agent may send the command over a network to the at least one IoT device. The command may cause the at least one IoT device to change from a first state (e.g., power off, first channel, first temperature, etc.) to a second state (e.g., power on, second channel, second temperature, etc.). In the context of FIGS. **3-4**, the agent **302** may cause a state change associated with the first light **310***c* by sending a message over the network **404***a* that includes an identifier associated with the first light **310***c*. In the example illustrated in FIG. **5**, the agent **302'** may detect **524** a state change associated with the first IoT device **310'**, for example, based on the input **525**. In one aspect, the agent **302'** may cause the state change to the IoT device **310'**.

At operation **706**, the agent may obtain, after the state change of the at least one IoT device, second image data representing the first location. For example, the agent may request, from a camera, second image data that represents the first location that includes the set of objects. Based on the request, the agent may receive the second image data that represents the first location. In the context of FIGS. **3-4**, the agent **302** may obtain second image data **428** representing the location **300** that includes the set of objects **310***a-e*, **312***a-k*. For example, the agent **302** may obtain the second image data **428** over a network **404***b*, e.g., from a device that is communicatively coupled with the agent **302**. In the example illustrated in FIG. **5**, the agent **302'** may obtain second image data **526** representing the location **300** that includes the set of objects **310***a-e* (**310'**), **312***a-k*. In an aspect, the agent **302/302'** may obtain the second image data through the camera **506**.

At operation **708**, the agent may compare may compare the first image data to the second image data in order to detect one or more differences. For example, the agent may determine that the at least one IoT device is now in an "on" state based on the difference between the first image data (representing the at least one IoT device in an "off" state) and the second image data (representing the at least one IoT device in an "on" state), and the agent may determine that an identifier (and associated stored registration information) for at least one IoT device corresponds to the representation of the at least one IoT device in the first image data and/or the second image data.

In the context of FIGS. **3-4**, the agent **302** may compare the second image data **428** to the first image data **426** in order to identify a difference between the second image data **428** and the first image data **426**, and to identify the first light **310***c* that corresponds to the IoT device represented with the identified difference (e.g., the first light **310***c* is powered off in the first image data **426** but powered on in the second image data **428** may be identified). Accordingly, the agent **302** may store visual and/or spatial attributes and/or relationships corresponding to the first light **310***c* represented in the first image data **426** and/or the second image data **428**. In the example illustrated in FIG. **5**, the agent **302'** may determine **528** attributes of the IoT device **310'** based on comparing the first image data **520** with the second image data **526**.

With reference to FIG. **8**, a flowchart illustrates one method **800** that is one aspect of operation **614**, in which the agent may determine whether the input corresponds to the at least one IoT device based on the stored registration information associated with the at least one IoT device. At operation **802**, the agent may process the input to determine an input set of attributes and an instruction. In various aspects, the input may be speech input, written input, and/or other input received by the agent (e.g., via a device communicatively coupled with the agent). For example, the agent may obtain a speech input (e.g., natural language input) that describes at least one IoT device (e.g., through a microphone) or image data (e.g., through a camera that depicts selection or identification (e.g., by a user) of the at least one IoT device. The agent may process or parse the input (e.g., using a neural network) to determine an input set of attributes and an input instruction. In the context of FIGS. **3-4**, the agent **302** may process **432** a command **430** received over a network **404***b*. For example, the agent **302** may process **432** the command **430** to identify an input set of attributes and an input command. In the example illustrated in FIG. **5**, the agent **302'** may obtain an IoT-control input **532** (e.g., through a camera **506** and/or microphone **508**) associated with the first IoT device **310'**.

At operation **804**, the agent may identify the first identifier associated with the at least one IoT device based on correspondence between the input set of attributes and the first set of attributes stored for the at least one IoT device. For example, the agent may compare the input set of attributes to one or more registered sets of attributes (e.g., stored as registration information for the at least one IoT device). The agent may determine whether the input set of attributes at least partially matches a stored set of attributes. If the agent determines that the input set of attributes at least partially matches a stored set of attributes, then the agent may identify the first identifier that corresponds to the matching registered set of attributes. Accordingly, the agent may send an instruction message to the identifier at least one IoT device, and the instruction message may include the first identifier and indicate the input command in order to control the at least one IoT device. In the context of FIGS. **3-4**, the agent **302** may process **432** the command **430** to determine whether an input set of attributes included in the command

430 at least partially matches the stored set of attributes associated with the first light **310***c*. When the input set of attributes included in the command **430** at least partially matches the stored set of attributes associated with the first light **310***c*, the agent **302** may send an instruction **434** to the first light **310***c*. The agent may generate the instruction **434** to include the identifier associated with the first light **310***c* and the input command in order to control the first light **310***c*. In the example illustrated in FIG. **5**, the agent **302'** may identify the first identifier corresponding to the first IoT device **310'** based on IoT-control input **532** and the stored registration information (e.g., storage **530**).

In one configuration, an agent, neural network, machine-learning model, computational network, processor, apparatus or other system is configured to identify each object of a set of objects included in a first location, and the set of objects may include at least one IoT device and at least one other object. The agent, neural network, machine-learning model, computational network, processor, apparatus or other system is further configured to determine a first set of attributes for the at least one IoT device, and the first set of attributes may indicate a first spatial relationship between the at least one IoT device and the at least one other object. The agent, neural network, machine-learning model, computational network, processor, apparatus or other system is further configured to store registration information associated with the at least one IoT device, and the registration information may include a first identifier associated with the at least one IoT device and may include the first set of attributes for the at least one IoT device. The agent, neural network, machine-learning model, computational network, processor, apparatus or other system is further configured to obtain an input. The agent, neural network, machine-learning model, computational network, processor, apparatus or other system is further configured to determine whether the input corresponds to the at least one IoT device based on the registration information associated with the at least one IoT device. The agent, neural network, machine-learning model, computational network, processor, apparatus or other system is further configured to control the at least one IoT device when the input corresponds to the at least one IoT device.

The agent, neural network, machine-learning model, computational network, processor, apparatus or other system may include means for identifying each object of a set of objects included in a first location, and the set of objects may include at least one IoT device and at least one other object. The means for identifying each object of a set of objects included in a first location may be the general-purpose processor **102**, program memory associated with the general-purpose processor **102**, and/or memory block **118** configured to perform the functions recited. In another configuration, the means for identifying each object of a set of objects included in a first location may be any module, any component, and/or any apparatus configured to perform the functions recited by the aforementioned means, such as the agent **302/302'** or a component thereof.

The agent, neural network, machine-learning model, computational network, processor, apparatus or other system may include means for determining a first set of attributes for the at least one IoT device, and the first set of attributes may indicate a first spatial relationship between the at least one IoT device and the at least one other object. The means for determining a first set of attributes for the at least one IoT device may be the general-purpose processor **102**, program memory associated with the general-purpose processor **102**, and/or memory block **118** configured to perform the functions recited. In another configuration, the means for determining a first set of attributes for the at least one IoT device may be any module, any component, and/or any apparatus configured to perform the functions recited by the aforementioned means, such as the agent **302/302'** or a component thereof.

The agent, neural network, machine-learning model, computational network, processor, apparatus or other system may include means for storing registration information associated with the at least one IoT device, and the registration information may include a first identifier associated with the at least one IoT device and may include the first set of attributes for the at least one IoT device. The means for storing registration information associated with the at least one IoT device may be the general-purpose processor **102**, program memory associated with the general-purpose processor **102**, and/or memory block **118** configured to perform the functions recited. In another configuration, the means for storing registration information associated with the at least one IoT device may be any module, any component, and/or any apparatus configured to perform the functions recited by the aforementioned means, such as the agent **302/302'** or a component thereof.

The agent, neural network, machine-learning model, computational network, processor, apparatus or other system may include means for obtaining an input. The means for obtaining an input may be the general-purpose processor **102**, program memory associated with the general-purpose processor **102**, and/or memory block **118** configured to perform the functions recited. In another configuration, the obtaining an input may be any module, any component, and/or any apparatus configured to perform the functions recited by the aforementioned means, such as the agent **302/302'** or a component thereof.

The agent, neural network, machine-learning model, computational network, processor, apparatus or other system may include means for determining whether the input corresponds to the at least one IoT device based on the registration information associated with the at least one IoT device. The means for determining whether the input corresponds to the at least one IoT device based on the registration information associated with the at least one IoT device may be the general-purpose processor **102**, program memory associated with the general-purpose processor **102**, and/or memory block **118** configured to perform the functions recited. In another configuration, the means for determining whether the input corresponds to the at least one IoT device based on the registration information associated with the at least one IoT device may be any module, any component, and/or any apparatus configured to perform the functions recited by the aforementioned means, such as the agent **302/302'** or a component thereof.

The agent, neural network, machine-learning model, computational network, processor, apparatus or other system may include means for controlling the at least one IoT device when the input corresponds to the at least one IoT device. The means for controlling the at least one IoT device when the input corresponds to the at least one IoT device may be the general-purpose processor **102**, program memory associated with the general-purpose processor **102**, and/or memory block **118** configured to perform the functions recited. In another configuration, the means for controlling the at least one IoT device when the input corresponds to the at least one IoT device may be any module, any component, and/or any apparatus configured to perform the functions recited by the aforementioned means, such as the agent **302/302'** or a component thereof.

The agent, neural network, machine-learning model, computational network, processor, apparatus or other system may include means for receiving, over a network, information associated with the at least one IoT device, the information including at least an identifier associated with the at least one IoT device. The means for receiving, over a network, information associated with the at least one IoT device, the information including at least an identifier associated with the at least one IoT device may be the general-purpose processor **102**, program memory associated with the general-purpose processor **102**, and/or memory block **118** configured to perform the functions recited. In another configuration, the means for receiving, over a network, information associated with the at least one IoT device, the information including at least an identifier associated with the at least one IoT device may be any module, any component, and/or any apparatus configured to perform the functions recited by the aforementioned means, such as the agent **302/302'** or a component thereof.

The agent, neural network, machine-learning model, computational network, processor, apparatus or other system may include means for determining to identify a set of IoT devices. The means for determining to identify a set of IoT devices may be the general-purpose processor **102**, program memory associated with the general-purpose processor **102**, and/or memory block **118** configured to perform the functions recited. In another configuration, the means for determining to identify a set of IoT devices may be any module, any component, and/or any apparatus configured to perform the functions recited by the aforementioned means, such as the agent **302/302'** or a component thereof.

According to certain aspects of the present disclosure, a local processing unit may be configured to determine parameters of the model based upon desired one or more functional features of the model, and develop the one or more functional features towards the desired functional features as the determined parameters are further adapted, tuned and updated.

In some aspects, the methods **400**, **500**, **600**, **700**, **800** may be performed by the SOC **100** (FIG. **1**). That is, each of the operations of methods **400**, **500**, **600**, **700**, **800** may, for example, but without limitation, be performed by the SOC **100** or one or more processors (e.g., CPU **102**) and/or other components included therein.

The various operations of methods described above may be performed by any suitable means capable of performing the corresponding functions. The means may include various hardware and/or software component(s) and/or module (s), including, but not limited to, a circuit, an application specific integrated circuit (ASIC), or processor. Generally, where there are operations illustrated in the figures, those operations may have corresponding counterpart means-plus-function components with similar numbering.

As used herein, the term “determining” encompasses a wide variety of actions. For example, “determining” may include calculating, computing, processing, deriving, investigating, looking up (e.g., looking up in a table, a database or another data structure), ascertaining and the like. Additionally, “determining” may include receiving (e.g., receiving information), accessing (e.g., accessing data in a memory) and the like. Furthermore, “determining” may include resolving, selecting, choosing, establishing and the like.

As used herein, a phrase referring to “at least one of” a list of items refers to any combination of those items, including single members. As an example, “at least one of: a, b, or c” is intended to cover: a, b, c, a-b, a-c, b-c, and a-b-c.

The various illustrative logical blocks, modules and circuits described in connection with the present disclosure may be implemented or performed with a general-purpose processor, a digital signal processor (DSP), an application specific integrated circuit (ASIC), a field programmable gate array signal (FPGA) or other programmable logic device (PLD), discrete gate or transistor logic, discrete hardware components or any combination thereof designed to perform the functions described herein. A general-purpose processor may be a microprocessor, but in the alternative, the processor may be any commercially available processor, controller, microcontroller or state machine. A processor may also be implemented as a combination of computing devices, e.g., a combination of a DSP and a microprocessor, a plurality of microprocessors, one or more microprocessors in conjunction with a DSP core, or any other such configuration.

The steps of a method or algorithm described in connection with the present disclosure may be embodied directly in hardware, in a software module executed by a processor, or in a combination of the two. A software module may reside in any form of storage medium that is known in the art. Some examples of storage media that may be used include random access memory (RAM), read only memory (ROM), flash memory, erasable programmable read-only memory (EPROM), electrically erasable programmable read-only memory (EEPROM), registers, a hard disk, a removable disk, a CD-ROM and so forth. A software module may include a single instruction, or many instructions, and may be distributed over several different code segments, among different programs, and across multiple storage media. A storage medium may be coupled to a processor such that the processor can read information from, and write information to, the storage medium. In the alternative, the storage medium may be integral to the processor.

The methods disclosed herein include one or more steps or actions for achieving the described method. The method steps and/or actions may be interchanged with one another without departing from the scope of the claims. In other words, unless a specific order of steps or actions is specified, the order and/or use of specific steps and/or actions may be modified without departing from the scope of the claims.

The functions described may be implemented in hardware, software, firmware, or any combination thereof. If implemented in hardware, an example hardware configuration may include a processing system in a device. The processing system may be implemented with a bus architecture. The bus may include any number of interconnecting buses and bridges depending on the specific application of the processing system and the overall design constraints. The bus may link together various circuits including a processor, machine-readable media, and a bus interface. The bus interface may be used to connect a network adapter, among other things, to the processing system via the bus. The network adapter may be used to implement signal processing functions. For certain aspects, a user interface (e.g., keypad, display, mouse, joystick, etc.) may also be connected to the bus. The bus may also link various other circuits such as timing sources, peripherals, voltage regulators, power management circuits, and the like, which are well known in the art, and therefore, will not be described any further.

The processor may be responsible for managing the bus and general processing, including the execution of software stored on the machine-readable media. The processor may be implemented with one or more general-purpose and/or special-purpose processors. Examples include microprocessors, microcontrollers, DSP processors, and other circuitry that can execute software. Software shall be construed broadly to mean instructions, data, or any combination thereof, whether referred to as software, firmware, middleware, microcode, hardware description language, or otherwise. Machine-readable media may include, by way of example, random access memory (RAM), flash memory, read only memory (ROM), programmable read-only memory (PROM), erasable programmable read-only memory (EPROM), electrically erasable programmable Read-only memory (EEPROM), registers, magnetic disks, optical disks, hard drives, or any other suitable storage medium, or any combination thereof. The machine-readable media may be embodied in a computer-program product. The computer-program product may include packaging materials.

In a hardware implementation, the machine-readable media may be part of the processing system separate from the processor. However, as those skilled in the art will readily appreciate, the machine-readable media, or any portion thereof, may be external to the processing system. By way of example, the machine-readable media may include a transmission line, a carrier wave modulated by data, and/or a computer product separate from the device, all which may be accessed by the processor through the bus interface. Alternatively, or in addition, the machine-readable media, or any portion thereof, may be integrated into the processor, such as the case may be with cache and/or general register files. Although the various components discussed may be described as having a specific location, such as a local component, they may also be configured in various ways, such as certain components being configured as part of a distributed computing system.

The processing system may be configured as a general-purpose processing system with one or more microprocessors providing the processor functionality and external memory providing at least a portion of the machine-readable media, all linked together with other supporting circuitry through an external bus architecture. Alternatively, the processing system may include one or more neuromorphic processors for implementing the neuron models and models of neural systems described herein. As another alternative, the processing system may be implemented with an application specific integrated circuit (ASIC) with the processor, the bus interface, the user interface, supporting circuitry, and at least a portion of the machine-readable media integrated into a single chip, or with one or more field programmable gate arrays (FPGAs), programmable logic devices (PLDs), controllers, state machines, gated logic, discrete hardware components, or any other suitable circuitry, or any combination of circuits that can perform the various functionality described throughout this disclosure. Those skilled in the art will recognize how best to implement the described functionality for the processing system depending on the particular application and the overall design constraints imposed on the overall system.

The machine-readable media may include a number of software modules. The software modules include instructions that, when executed by the processor, cause the processing system to perform various functions. The software modules may include a transmission module and a receiving module. Each software module may reside in a single storage device or be distributed across multiple storage devices. By way of example, a software module may be loaded into RAM from a hard drive when a triggering event occurs. During execution of the software module, the processor may load some of the instructions into cache to increase access speed. One or more cache lines may then be

loaded into a general register file for execution by the processor. When referring to the functionality of a software module below, it will be understood that such functionality is implemented by the processor when executing instructions from that software module. Furthermore, it should be appreciated that aspects of the present disclosure result in improvements to the functioning of the processor, computer, machine, or other system implementing such aspects.

If implemented in software, the functions may be stored or transmitted over as one or more instructions or code on a computer-readable medium. Computer-readable media include both computer storage media and communication media including any medium that facilitates transfer of a computer program from one place to another. A storage medium may be any available medium that can be accessed by a computer. By way of example, and not limitation, such computer-readable media can include RAM, ROM, EEPROM, CD-ROM or other optical disk storage, magnetic disk storage or other magnetic storage devices, or any other medium that can be used to carry or store desired program code in the form of instructions or data structures and that can be accessed by a computer. Additionally, any connection is properly termed a computer-readable medium. For example, if the software is transmitted from a website, server, or other remote source using a coaxial cable, fiber optic cable, twisted pair, digital subscriber line (DSL), or wireless technologies such as infrared (IR), radio, and microwave, then the coaxial cable, fiber optic cable, twisted pair, DSL, or wireless technologies such as infrared, radio, and microwave are included in the definition of medium. Disk and disc, as used herein, include compact disc (CD), laser disc, optical disc, digital versatile disc (DVD), floppy disk, and Blu-ray® disc where disks usually reproduce data magnetically, while discs reproduce data optically with lasers. Thus, in some aspects computer-readable media may include non-transitory computer-readable media (e.g., tangible media). In addition, for other aspects computer-readable media may include transitory computer-readable media (e.g., a signal). Combinations of the above should also be included within the scope of computer-readable media.

Thus, certain aspects may include a computer program product for performing the operations presented herein. For example, such a computer program product may include a computer-readable medium having instructions stored (and/or encoded) thereon, the instructions being executable by one or more processors to perform the operations described herein. For certain aspects, the computer program product may include packaging material.

Further, it should be appreciated that modules and/or other appropriate means for performing the methods and techniques described herein can be downloaded and/or otherwise obtained by a user terminal and/or base station as applicable. For example, such a device can be coupled to a server to facilitate the transfer of means for performing the methods described herein. Alternatively, various methods described herein can be provided via storage means (e.g., RAM, ROM, a physical storage medium such as a compact disc (CD) or floppy disk, etc.), such that a user terminal and/or base station can obtain the various methods upon coupling or providing the storage means to the device. Moreover, any other suitable technique for providing the methods and techniques described herein to a device can be utilized.

It is to be understood that the claims are not limited to the precise configuration and components illustrated above. Various modifications, changes and variations may be made in the arrangement, operation and details of the methods and apparatus described above without departing from the scope of the claims.

What is claimed is:

1. A method of operation of a system, the method comprising:

obtaining first image data representing a location;

identifying each object of a set of objects included in the location;

obtaining second image data representing the location after a changing of a state of at least one Internet-of-Things (IoT) device;

identifying the at least one IoT device based on a difference between the first image data and the second image data;

storing registration information associated with the at least one IoT device, the registration information including a first identifier associated with the at least one IoT device and including a first set of attributes for the at least one IoT device;

matching a description associated with an input to the first set of attributes based on a representation indicating at least one of a spatial attribute or a visual attribute of the at least one IoT device in a location that includes the at least one IoT device, wherein the description indicates a spatial relationship between the at least one IoT device and at least one other object in the location; and

controlling operation of the at least one IoT device based on an instruction included in the input when the description is matched to the first set of attributes of the at least one IoT device.

2. The method of claim **1**, wherein the first set of attributes further comprises at least one of the visual attribute associated with the at least one IoT device or the spatial attribute associated with the at least one IoT device, and at least one of a classification associated with the at least one IoT device or a capability attribute associated with the at least one IoT device.

3. The method of claim **1**, further comprising:

processing the input to determine the description and the instruction; and

identifying the first identifier associated with the at least one IoT device based on matching the description to the first set of attributes,

wherein the first identifier is used for the controlling the operation of the at least one IoT.

4. The method of claim **1**, wherein the input comprises a natural language input.

5. The method of claim **1**, further comprising:

determining the first set of attributes for the at least one IoT device, the first set of attributes indicating the at least one of the spatial attribute or the visual attribute of the at least one IoT device in the location, wherein the set of objects includes the at least one IoT device.

6. The method of claim **1**, wherein the identifying each object of the set of objects included in the location comprises:

changing a state of the at least one IoT device.

7. The method of claim **1**, wherein the description is matched to the first set of attributes based on correspondence between the spatial relationship and the at least one of the spatial attribute or the visual attribute of the at least one IoT device in the location.

8. The method of claim **1**, further comprising:

determining to identify a set of IoT devices,

wherein the identifying each object of the set of objects included in the location is based on the determining to identify the set of IoT devices.

9. The method of claim **1**, further comprising:

receiving, over a network, information associated with the at least one IoT device, the information including at least the first identifier associated with the at least one IoT device; and

associating the first identifier with the first set of attributes for the at least one IoT device, wherein the operation of the at least one IoT device is controlled using the first identifier.

10. An apparatus for operating a system, the apparatus comprising:

means for obtaining first image data representing a location;

means for identifying each object of a set of objects included in the location;

means for obtaining second image data representing the location after a changing of a state of at least one Internet-of-Things (IoT) device;

means for identifying the at least one IoT device based on a difference between the first image data and the second image data;

means for storing registration information associated with the at least one IoT device, the registration information including a first identifier associated with the at least one IoT device and including a first set of attributes for the at least one IoT device;

means for matching a description associated with an input to the first set of attributes based on a representation indicating at least one of a spatial attribute or a visual attribute of the at least one IoT device in a location that includes the at least one IoT device, wherein the description indicates a spatial relationship between the at least one IoT device and at least one other object in the location; and

means for controlling operation of the at least one IoT device based on an instruction included in the input when the description is matched to the first set of attributes of the at least one IoT device.

11. The apparatus of claim **10**, wherein the first set of attributes further comprises at least one of the visual attribute associated with the at least one IoT device or the spatial attribute associated with the at least one IoT device, and at least one of a classification associated with the at least one IoT device or a capability attribute associated with the at least one IoT device.

12. The apparatus of claim **10**, further comprising:

means for processing the input to determine the description and the instruction; and

means for identifying the first identifier associated with the at least one IoT device based on matching the description to the first set of attributes,

wherein the first identifier is used for the controlling the operation of the at least one IoT device.

13. The apparatus of claim **10**, wherein the input comprises a natural language input.

14. The apparatus of claim **10**, further comprising:

means for determining the first set of attributes for the at least one IoT device, the first set of attributes indicating the at least one of the spatial attribute or the visual attribute of the at least one IoT device in the location, wherein the set of objects includes the at least one IoT device.

15. The apparatus of claim **10**, wherein the means for identifying each object of the set of objects included in the first location is configured to:

change a state of the at least one IoT device.

16. The apparatus of claim **10**, wherein the description is matched to the first set of attributes based on correspondence between the spatial relationship and the at least one of the spatial attribute or the visual attribute of the at least one IoT device in the location.

17. The apparatus of claim **10**, further comprising:

means for determining to identify a set of IoT devices,

wherein the identifying each object of the set of objects included in the location is based on the determining to identify the set of IoT devices.

18. The apparatus of claim **10**, further comprising:

means for receiving, over a network, information associated with the at least one IoT device, the information including at least the first identifier associated with the at least one IoT device; and

means for associating the first identifier with the first set of attributes for the at least one IoT device, wherein the operation of the at least one IoT device is controlled using the first identifier.

19. An apparatus for operating a system, the apparatus comprising:

a memory; and

at least one processor coupled to the memory and configured to:

obtain first image data representing a location;

identify each object of a set of objects included in the location;

obtain second image data representing the location after a changing of a state of at least one Internet-of-Things (IoT) device;

identify the at least one IoT device based on a difference between the first image data and the second image data;

store registration information associated with the at least one IoT device, the registration information including a first identifier associated with the at least one IoT device and including a first set of attributes for the at least one IoT device;

match a description associated with an input to the first set of attributes based on a representation indicating at least one of a spatial attribute or a visual attribute of the at least one IoT device in a location that includes the at least one IoT device, wherein the description indicates a spatial relationship between the at least one IoT device and at least one other object in the location; and

control operation of the at least one IoT device based on an instruction included in the input when the description is matched to the first set of attributes of the at least one IoT device.

20. The apparatus of claim **19**, wherein the first set of attributes further comprises at least one of the visual attribute associated with the at least one IoT device or the spatial attribute associated with the at least one IoT device, and at least one of a classification associated with the at least one IoT device or a capability attribute associated with the at least one IoT device.

21. The apparatus of claim **19**, wherein the at least one processor is further configured to:

process the input to determine the description and the instruction; and

identify the first identifier associated with the at least one IoT device based on matching the description to the first set of attributes,

wherein the first identifier is used for the controlling the operation of the at least one IoT device.

22. The apparatus of claim **19**, wherein the input comprises a natural language input.

23. The apparatus of claim **19**, wherein the at least one processor is further configured to:

determine the first set of attributes for the at least one IoT device, the first set of attributes indicating the at least one of the spatial attribute or the visual attribute of the at least one IoT device in the location, wherein the set of objects includes the at least one IoT device.

24. The apparatus of claim **19**, wherein the identification of each object of the set of objects included in the first location comprises to:

change a state of the at least one IoT device.

25. The apparatus of claim **19**, wherein the description is matched to the first set of attributes based on correspondence between the spatial relationship and the at least one of the spatial attribute or the visual attribute of the at least one IoT device in the location.

26. The apparatus of claim **19**, wherein the at least one processor is further configured to:

determine to identify a set of IoT devices,

wherein the identification of each object of the set of objects included in the location is based on the determination to identify the set of IoT devices.

27. The apparatus of claim **19**, wherein the at least one processor is further configured to:

receive, over a network, information associated with the at least one IoT device, the information including at least the first identifier associated with the at least one IoT device; and

associate the first identifier with the first set of attributes for the at least one IoT device, wherein the operation of the at least one IoT device is controlled using the first identifier.

28. A non-transitory, computer-readable medium storing computer-executable code for operation of a system, comprising code to:

obtain first image data representing a location;

identify each object of a set of objects included in the location;

obtain second image data representing the location after a changing of a state of at least one Internet-of-Things (IoT) device;

identify the at least one IoT device based on a difference between the first image data and the second image data;

store registration information associated with the at least one IoT device, the registration information including a first identifier associated with the at least one IoT device and including a first set of attributes for the at least one IoT device;

match a description associated with an input to the first set of attributes based on a representation indicating at least one of a spatial attribute or a visual attribute of the at least one IoT device in a location that includes the at least one IoT device, wherein the description indicates a spatial relationship between the at least one IoT device and at least one other object in the location; and

control operation of the at least one IoT device based on an instruction included in the input when the description is matched to the first set of attributes of the at least one IoT device.

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